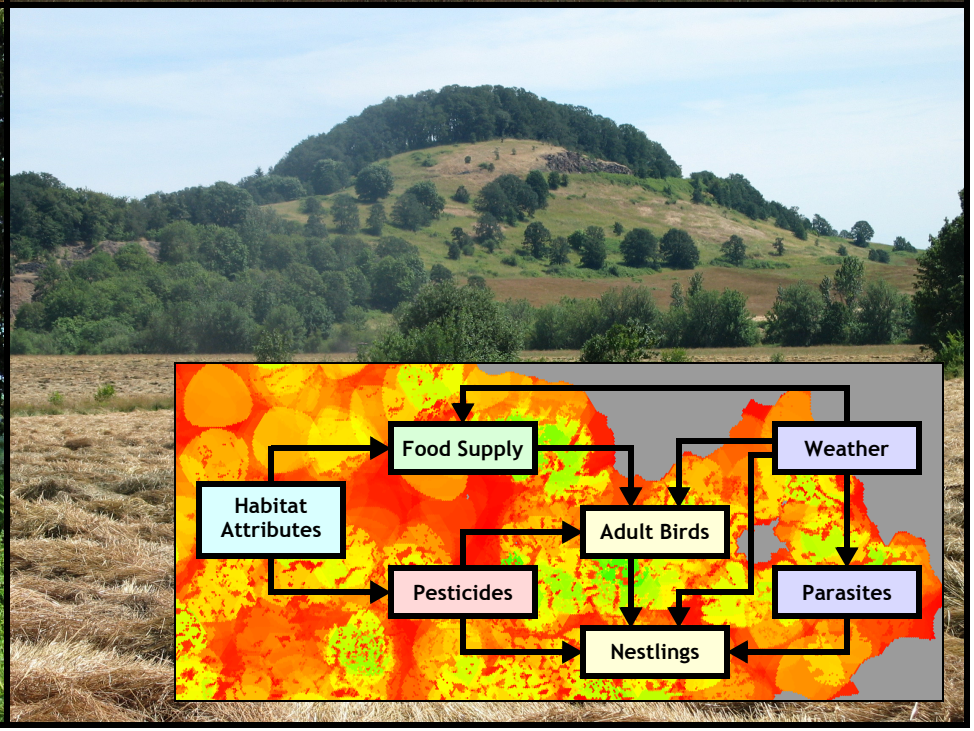
Integrating Landscapes Structure with Wildlife Life History and Stress

Nathan H. Schumaker



Introduction

Today's seminar will explore the influence of landscape structure from two different angles:

- **By examining some contrasts between simple and more complex wildlife models**
- **By exploring links between habitat quality, landscape structure, and population dynamics**

HexSim History

Has existed in some form for about 15 years now...

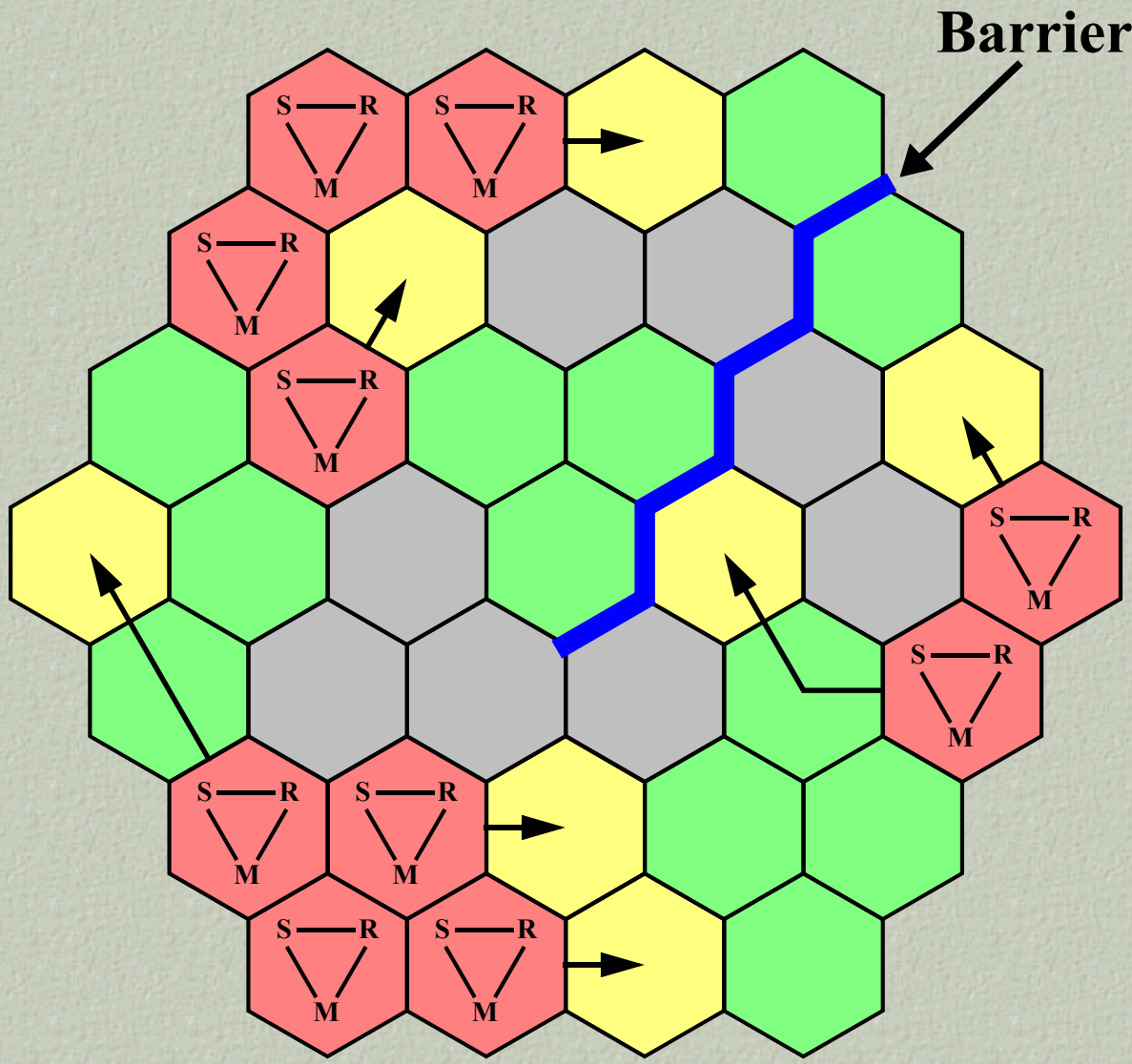
- **Circa 1992**
  Original version began as a grad student project
- **1995 - 2000**
  Focused mostly on landscape structure
- **2001 - Present**
  Expanded to address multiple species / stressors

What Is It?

A SEPM that attempts to balance realism, generality, and parsimony

- **Life cycle composed of user-defined events**
- **Most events have spatial drivers**
- **Individual-based, with traits that can change**
- **Simulations can range from simple to complex**

HexSim Basics



Non-Habitat

Available Habitat

Occupied Habitat

Colonized Habitat

Movement Path

S = Survival

R = Reproduction

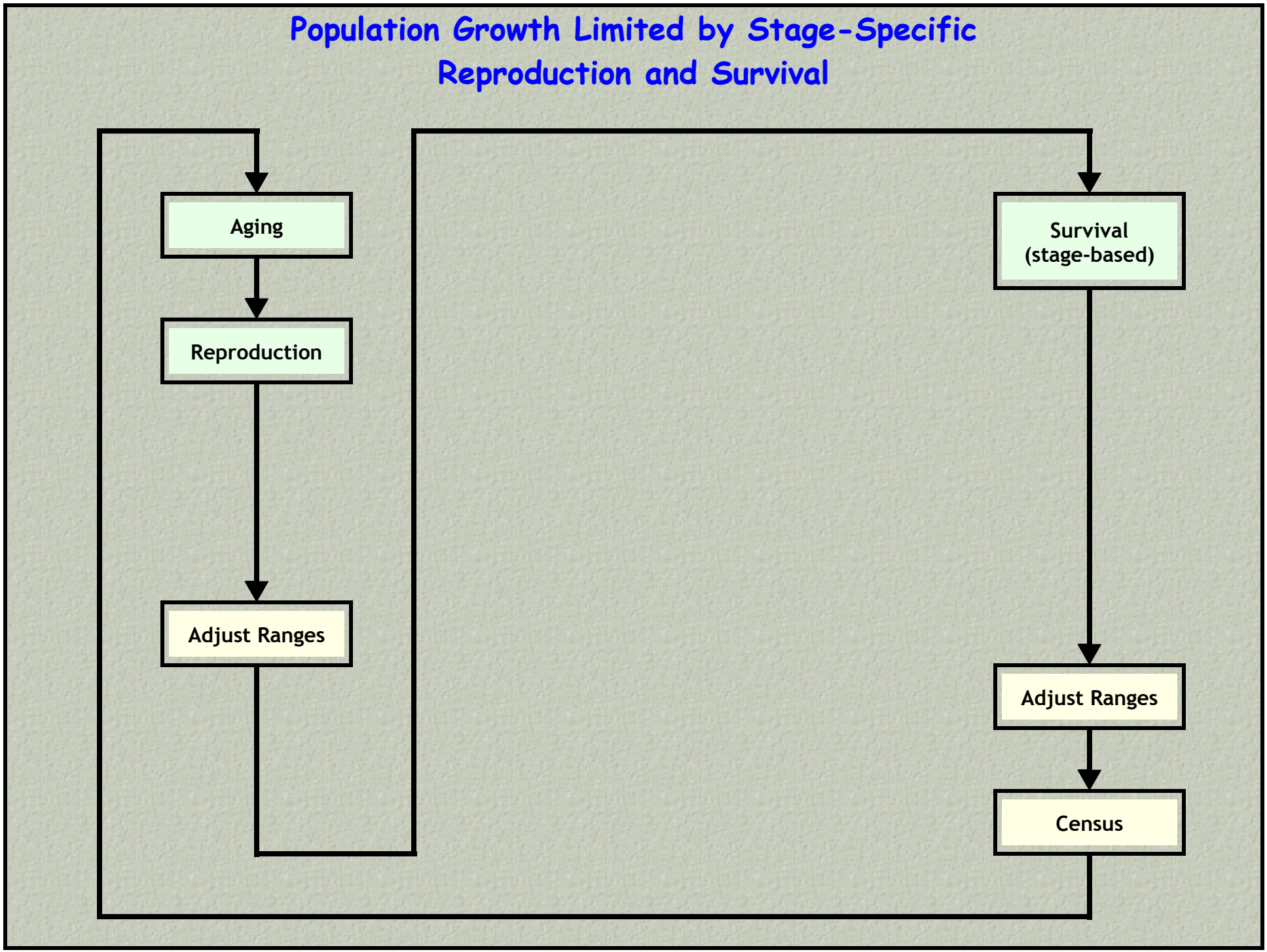
M = Movement

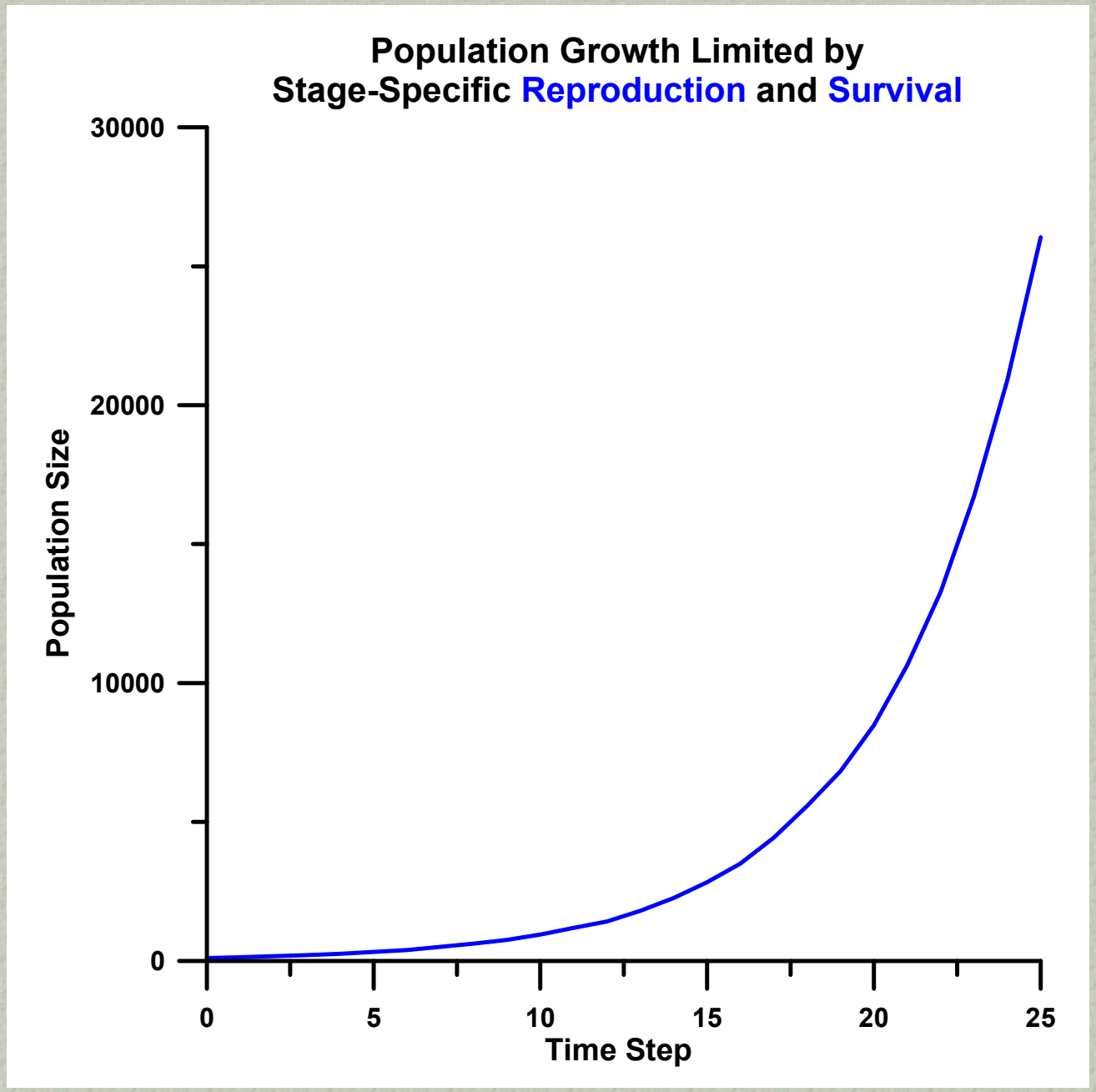
Start Simple

- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is not limiting

The result is exponential growth, with the growth rate tempered by the vital rates.

Population Growth Limited by Stage-Specific Reproduction and Survival



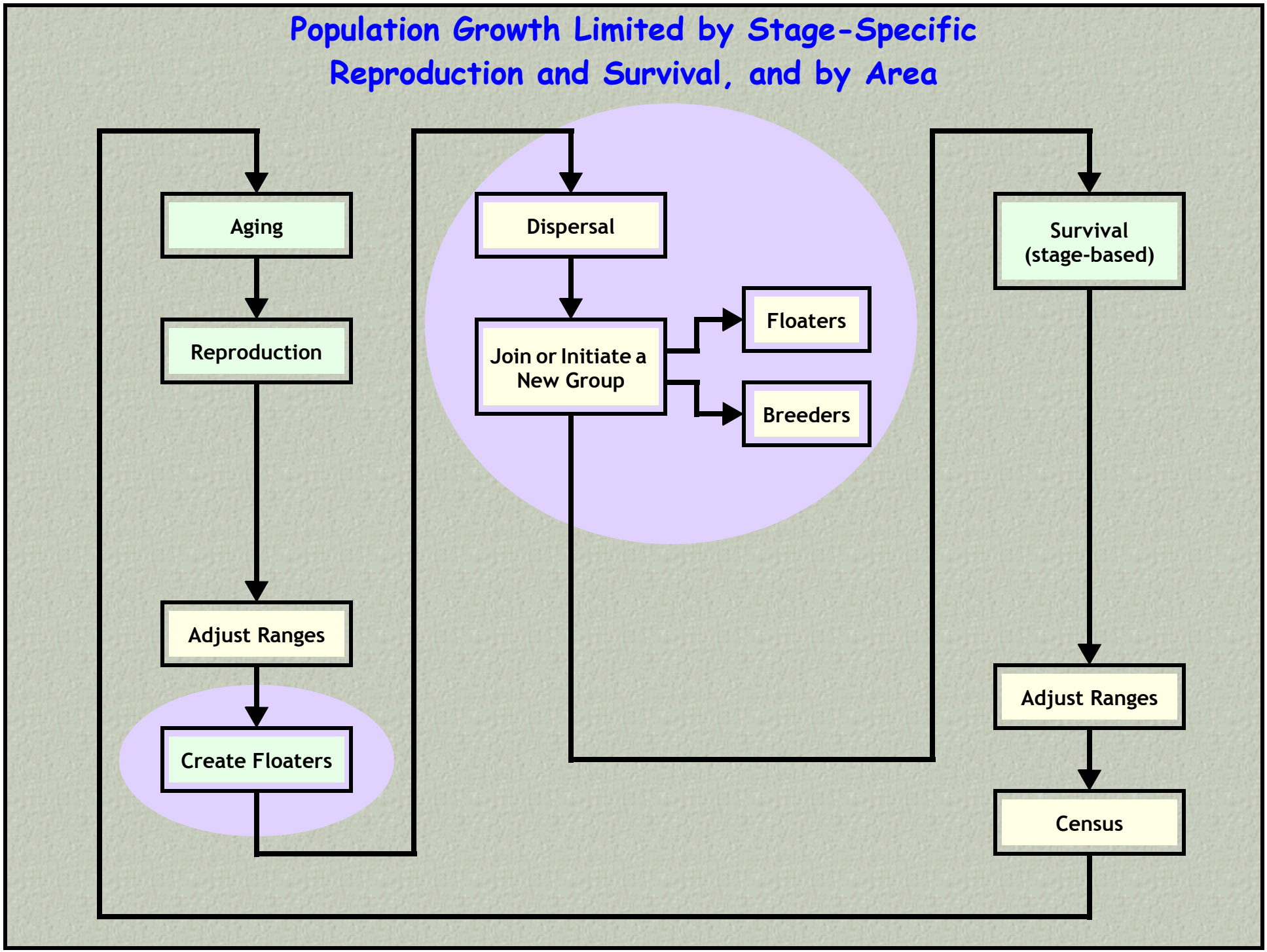

Population Growth Limited by
Stage-Specific Reproduction and Survival
30000
20000
10000
0
Population Size
0
5
10
15
20
25
Time Step

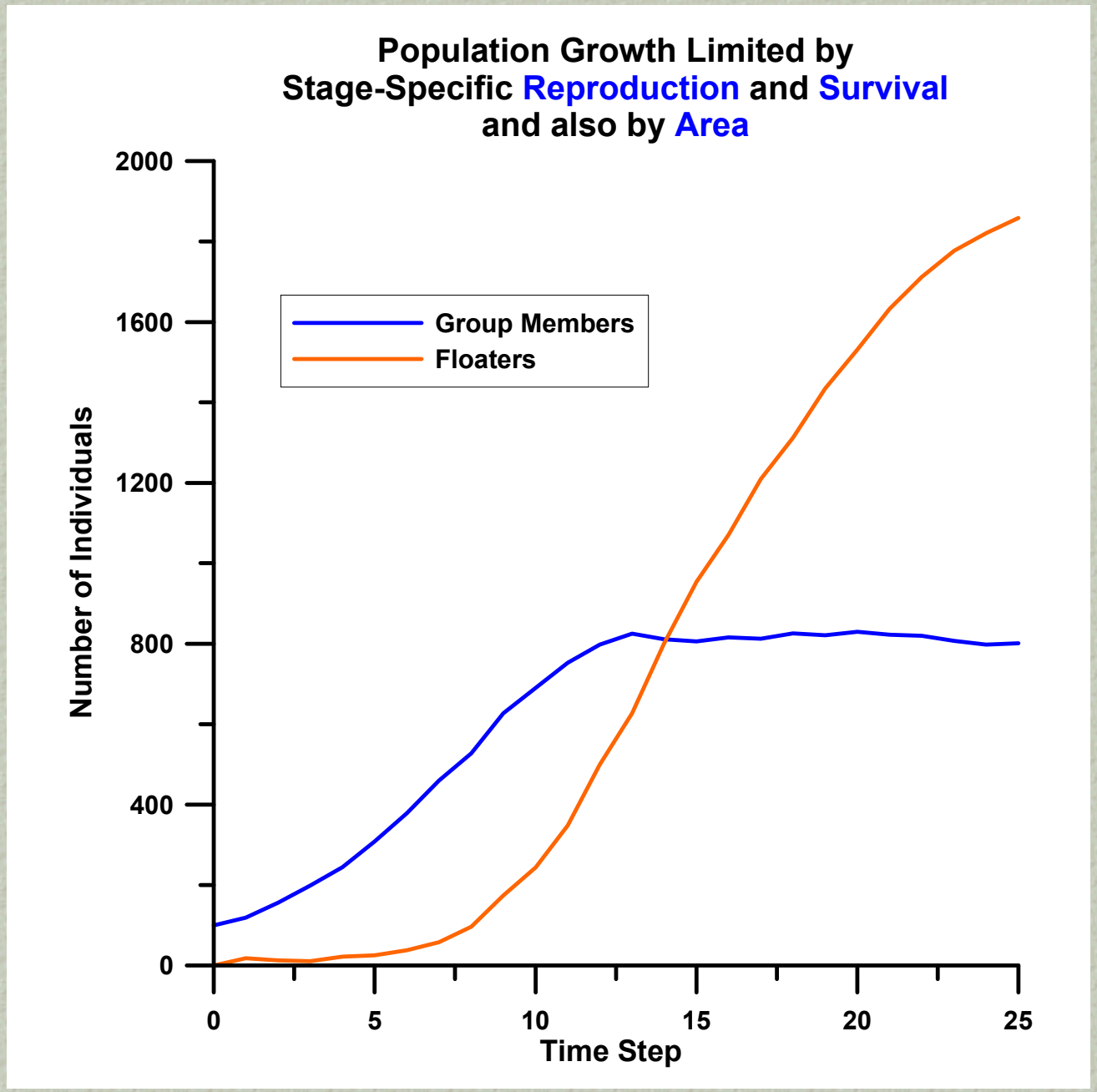
Add A Little Realism

- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is finite, but only affects reproduction

Two classes of individuals emerge -- Breeders & Floaters
Breeders need home ranges, which are in limited supply
Breeder populations reach a carrying capacity
Floater populations grow indefinitely

Population Growth Limited by Stage-Specific Reproduction and Survival, and by Area



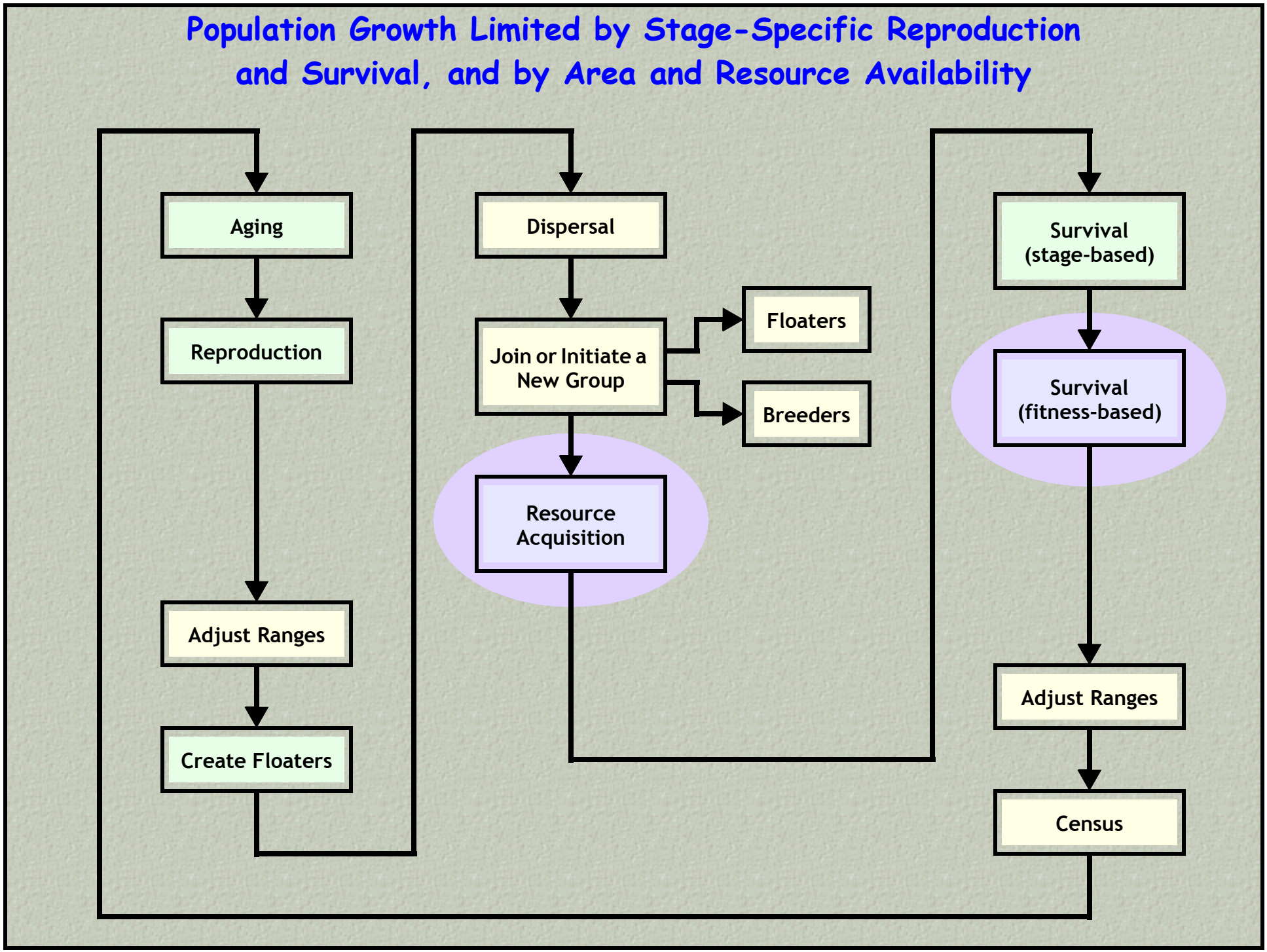

Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by Area
Group Members
Floaters
Number of Individuals
2000
1600
1200
800
400
0
0
5
10
15
20
25
Time Step

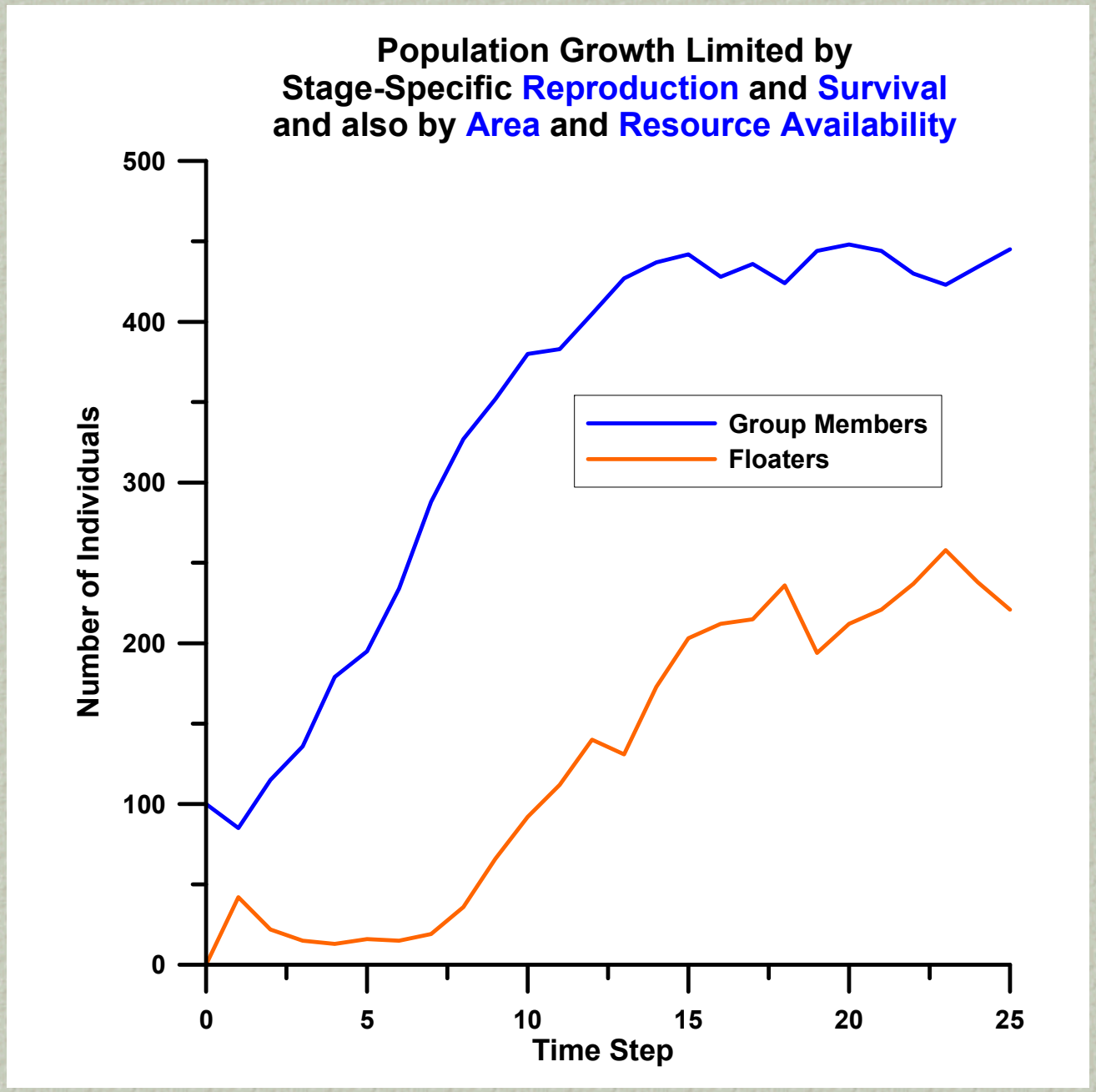
Add Additional Realism

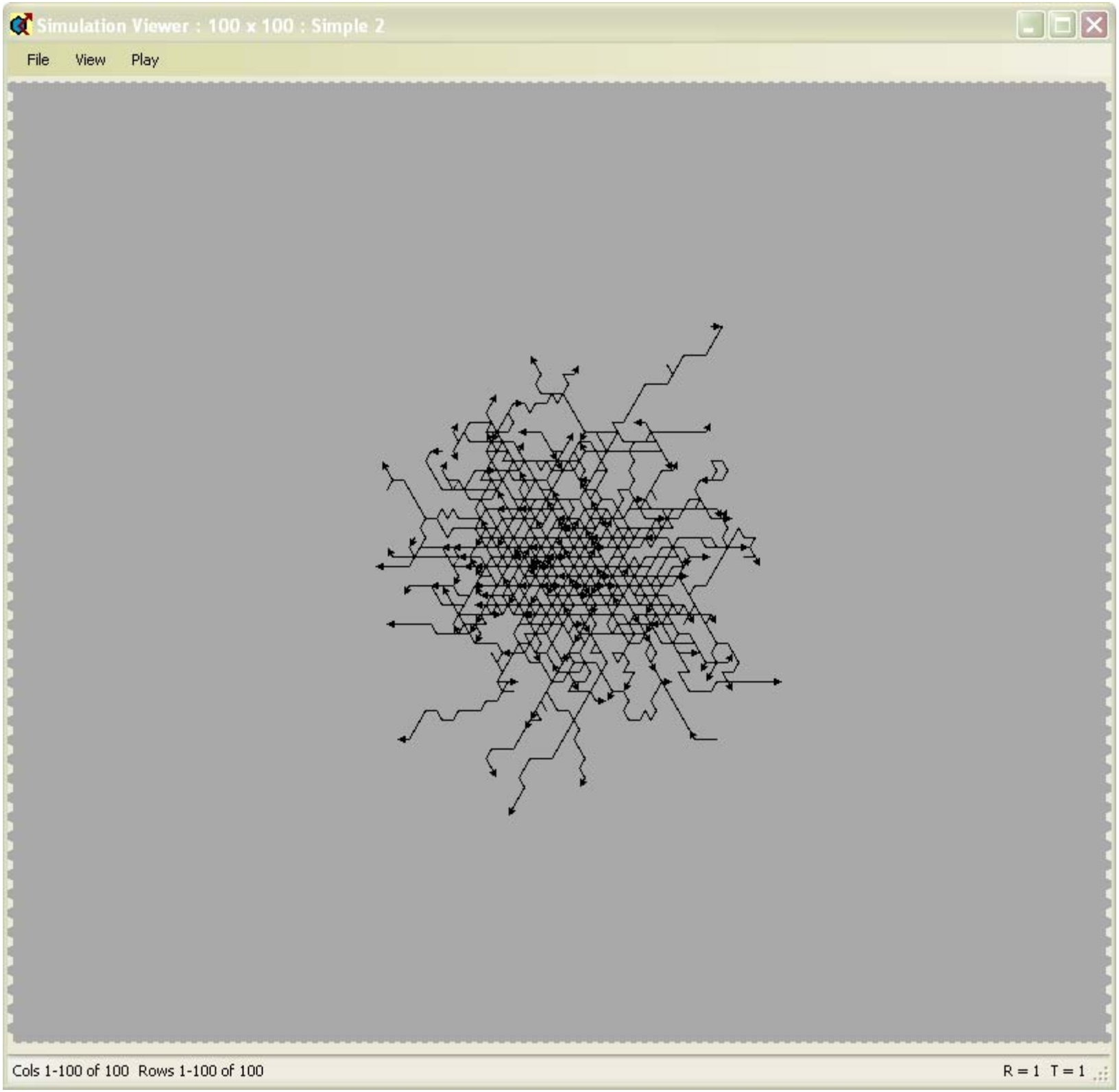
- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is finite, and affects survival & reproduction
- Resource acquisition is smoothed across 3 time steps
- Acquired fitness levels are low, medium, and high

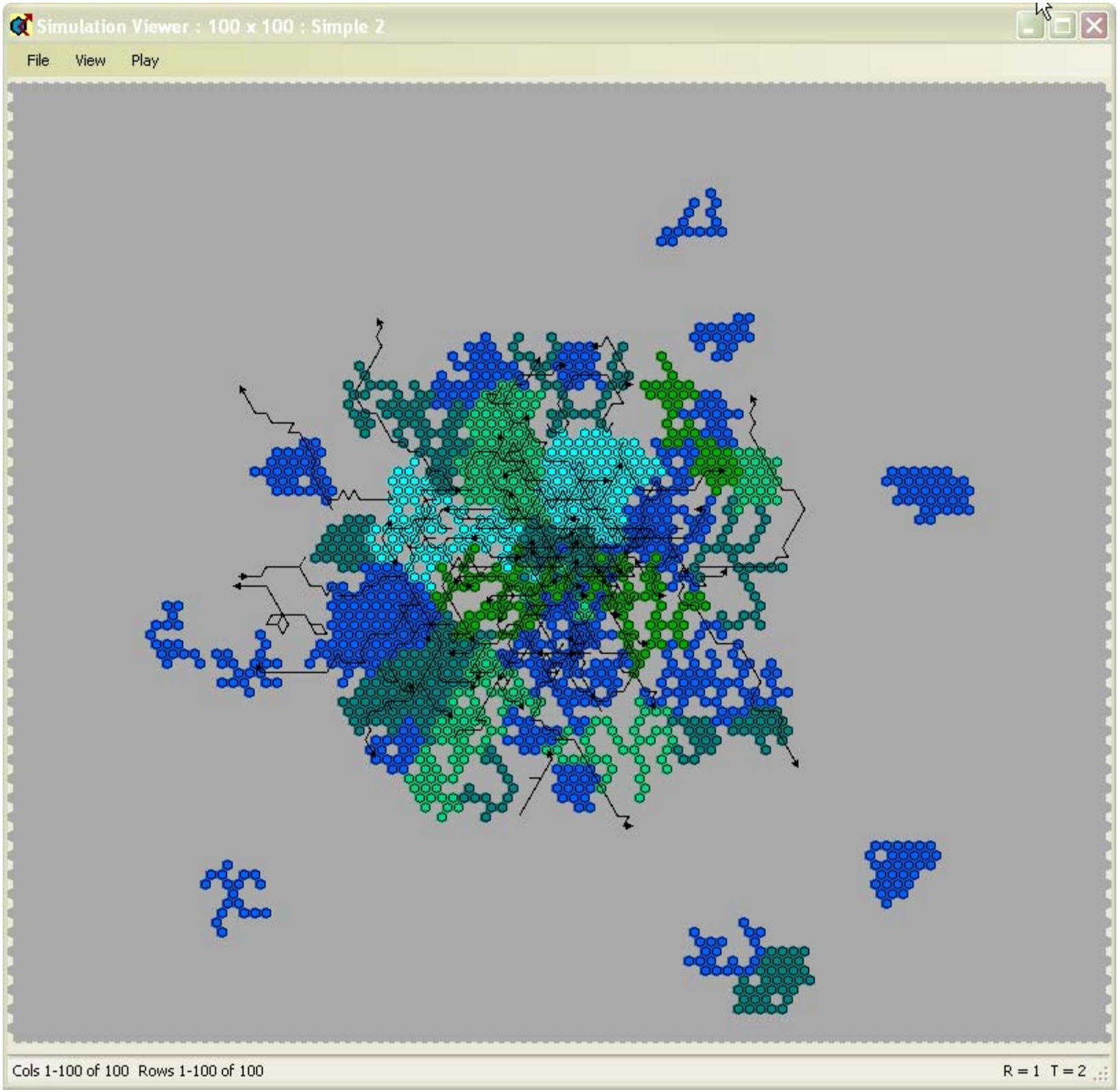
Both floaters and group members experience density-dependent growth and a carrying capacity

Population Growth Limited by Stage-Specific Reproduction and Survival, and by Area and Resource Availability




Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by Area and Resource Availability
Number of Individuals
500
400
300
200
100
0
0
5
10
15
20
25
Time Step
Group Members
Floaters


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 1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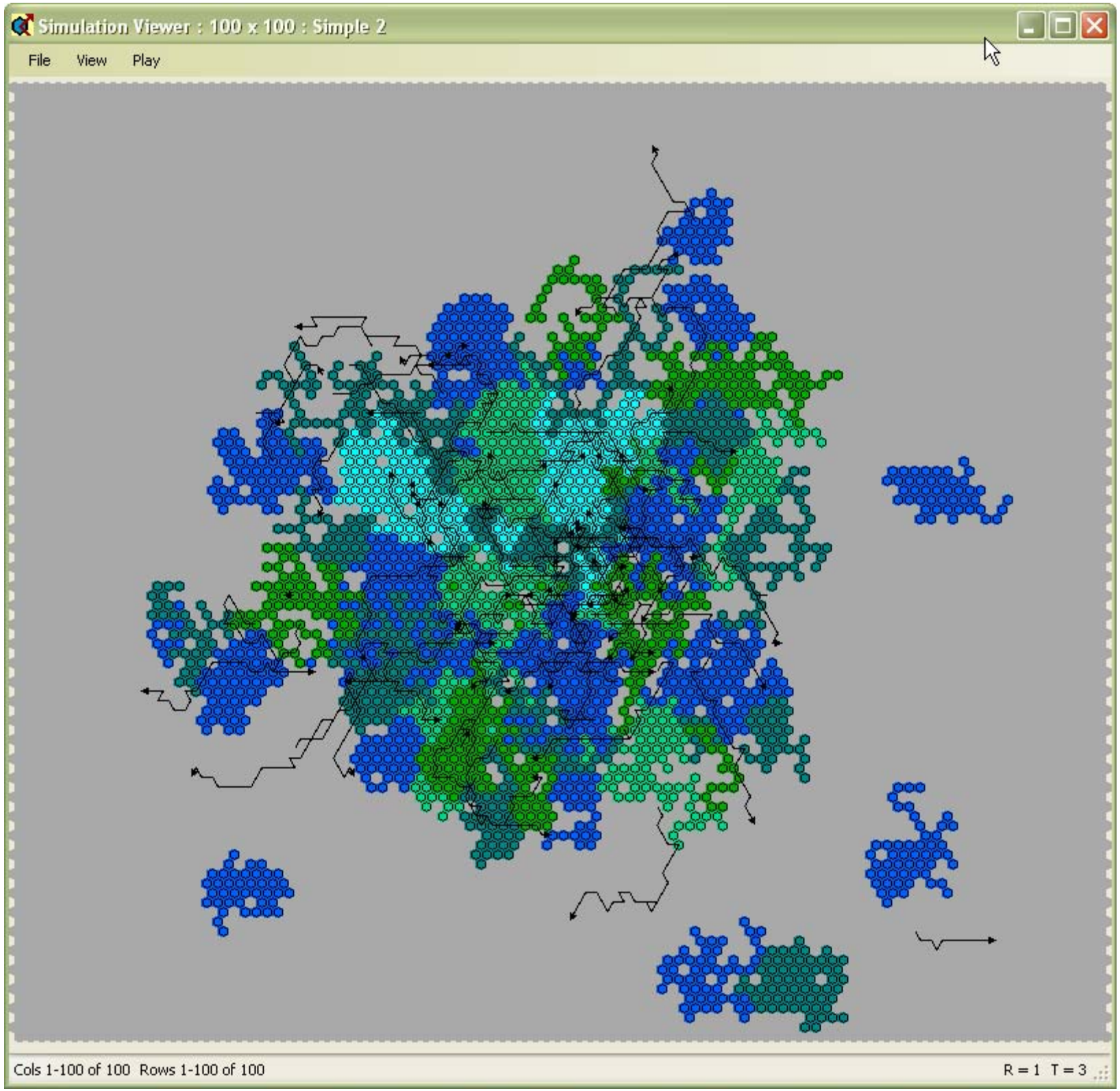
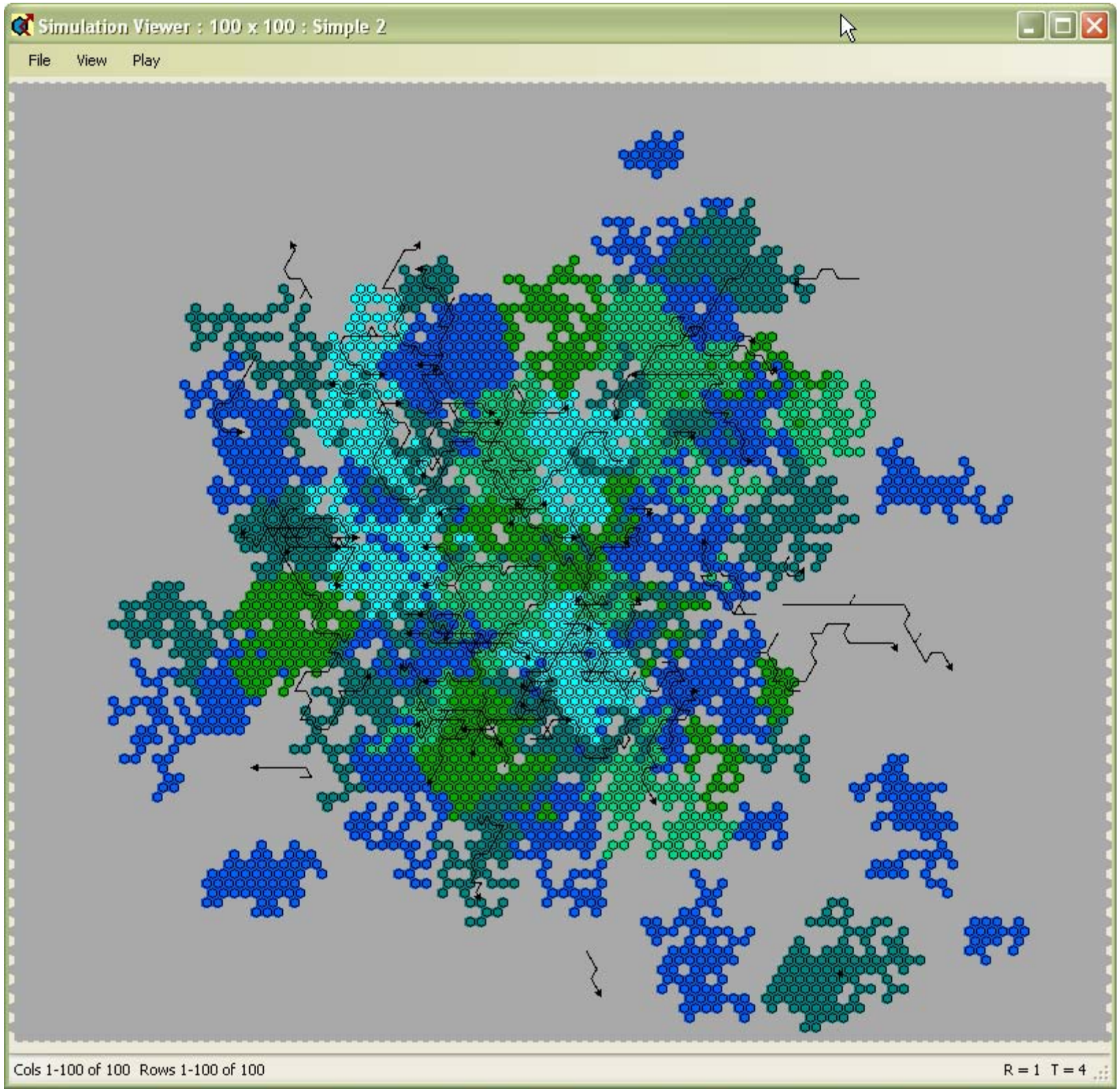
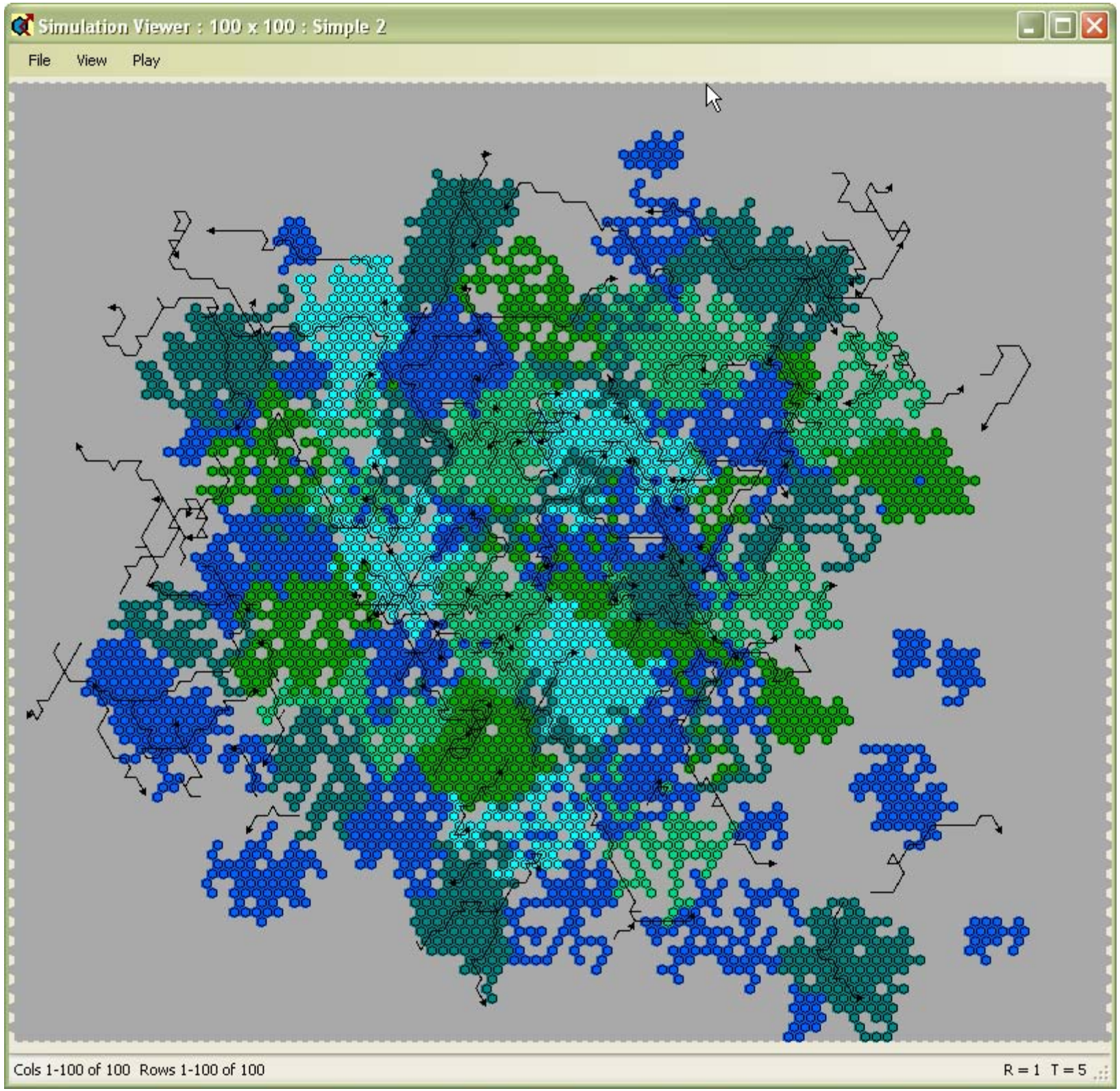
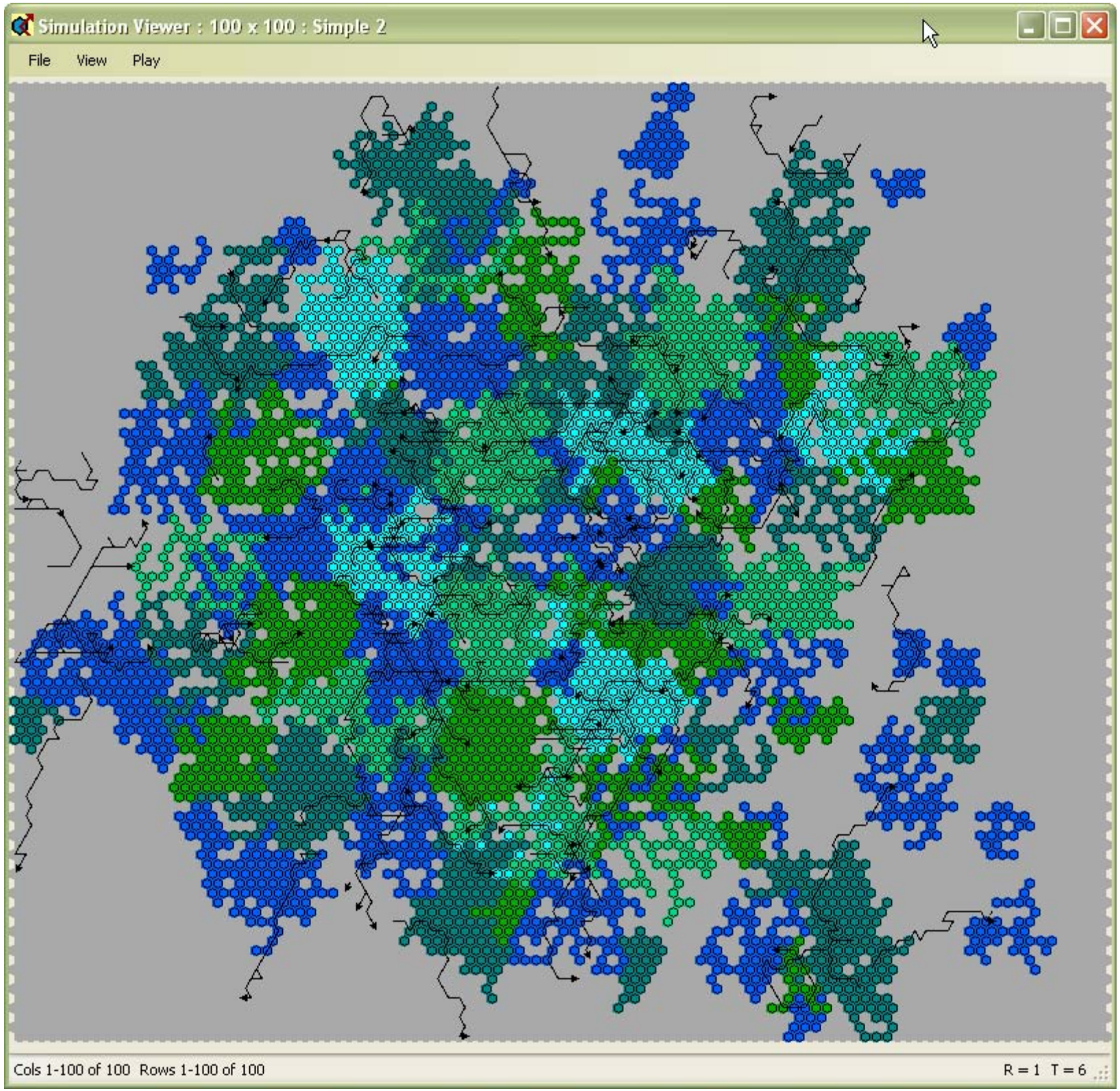
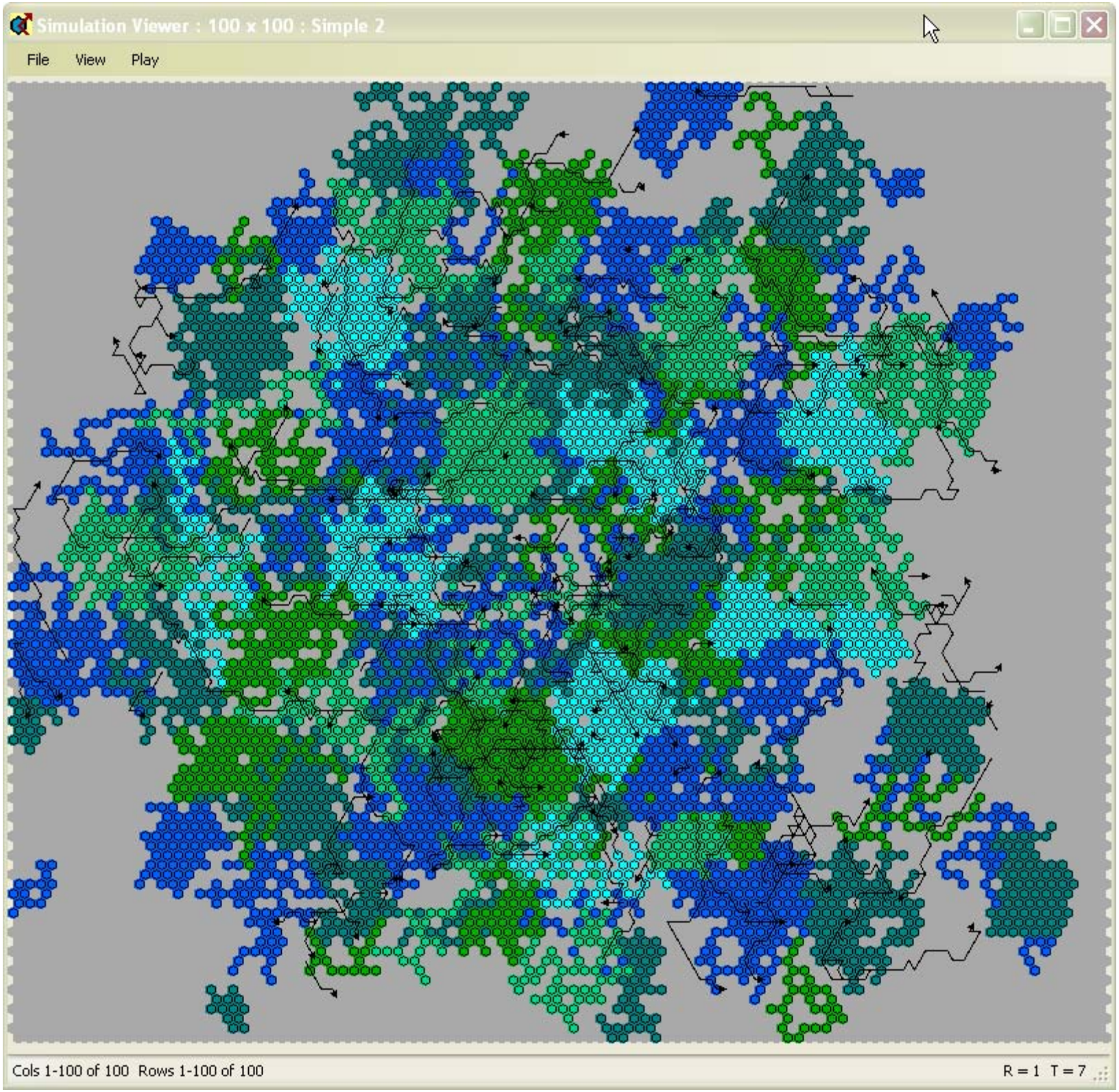
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 2

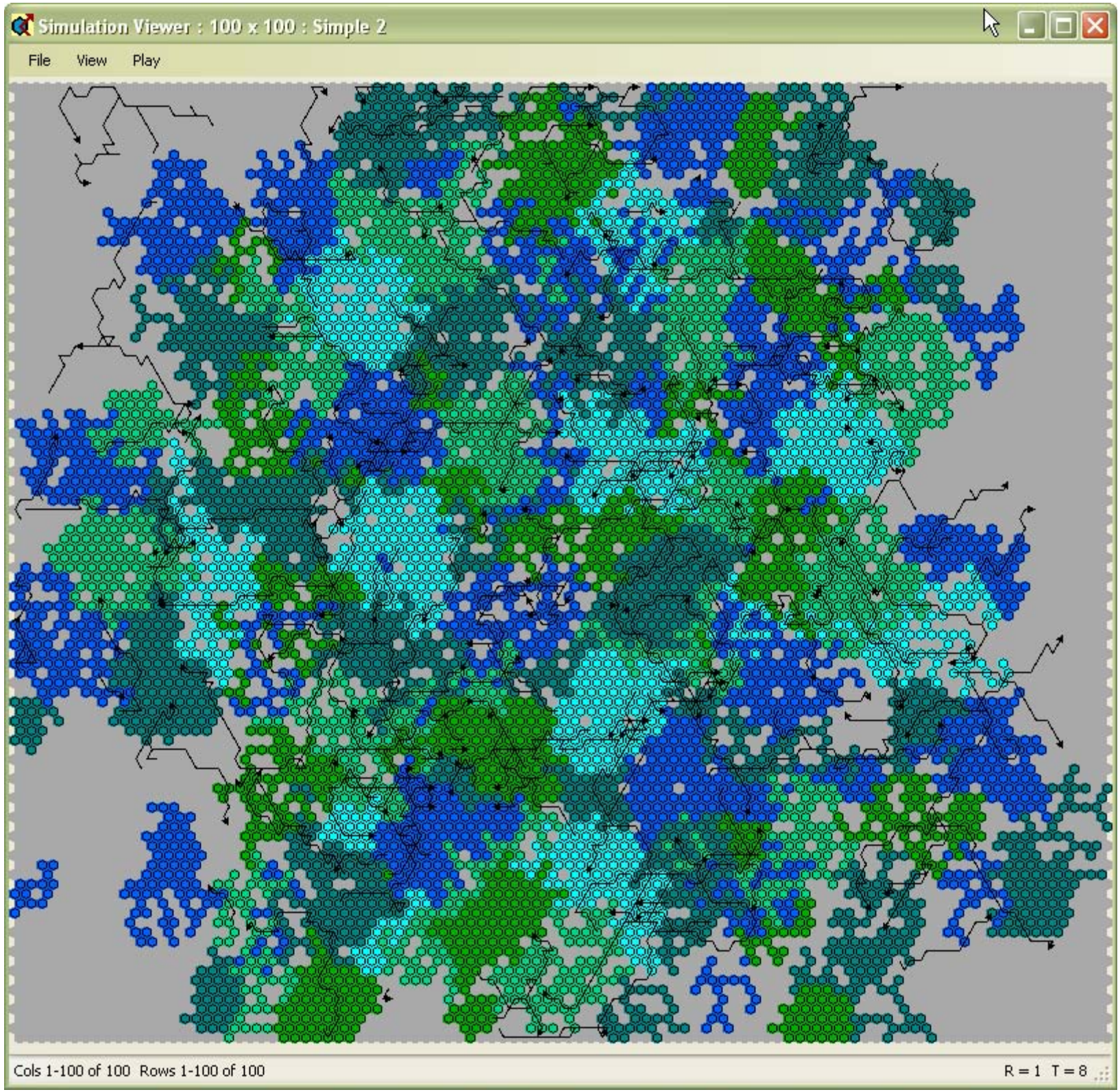

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 3

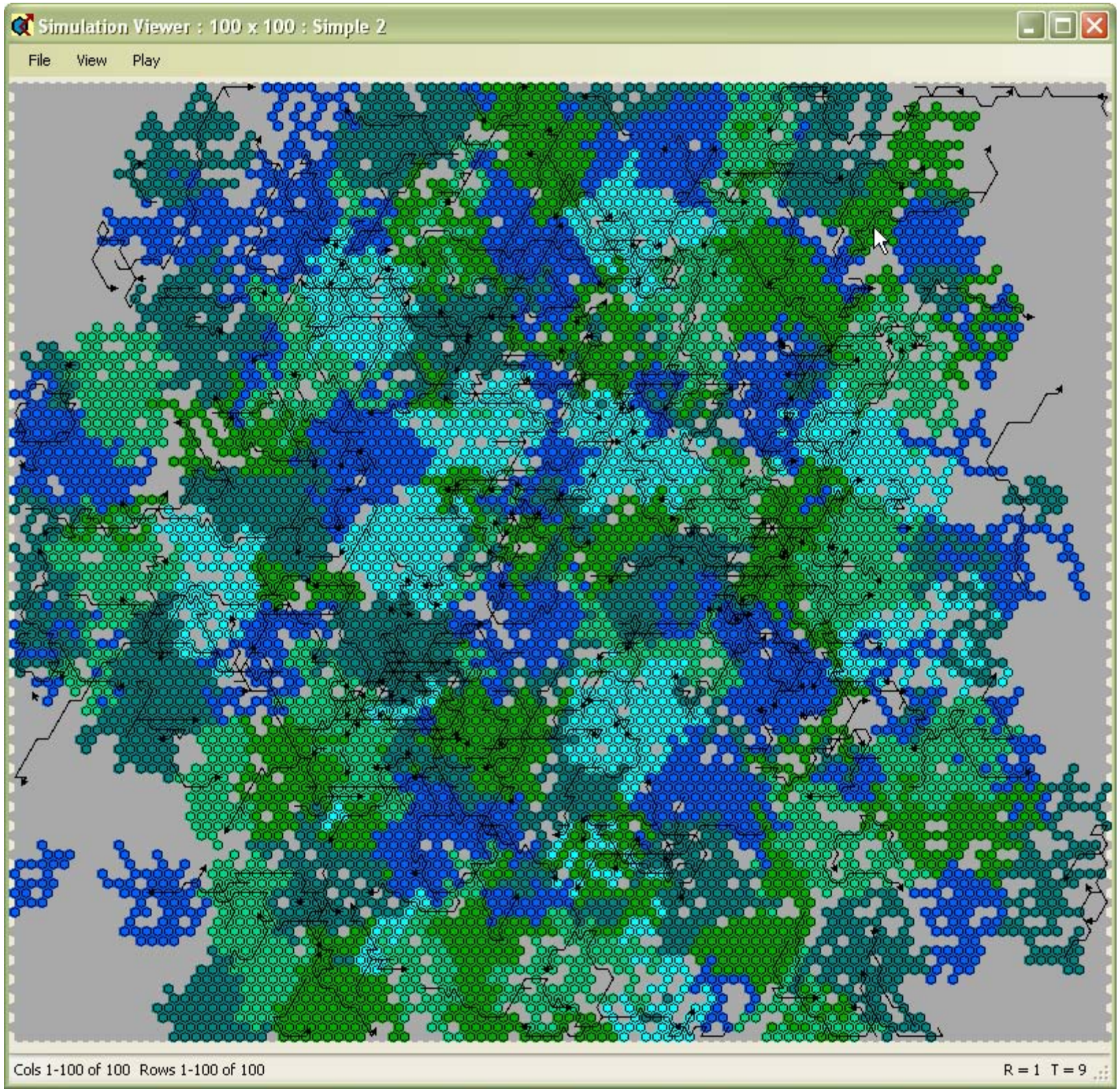

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 4

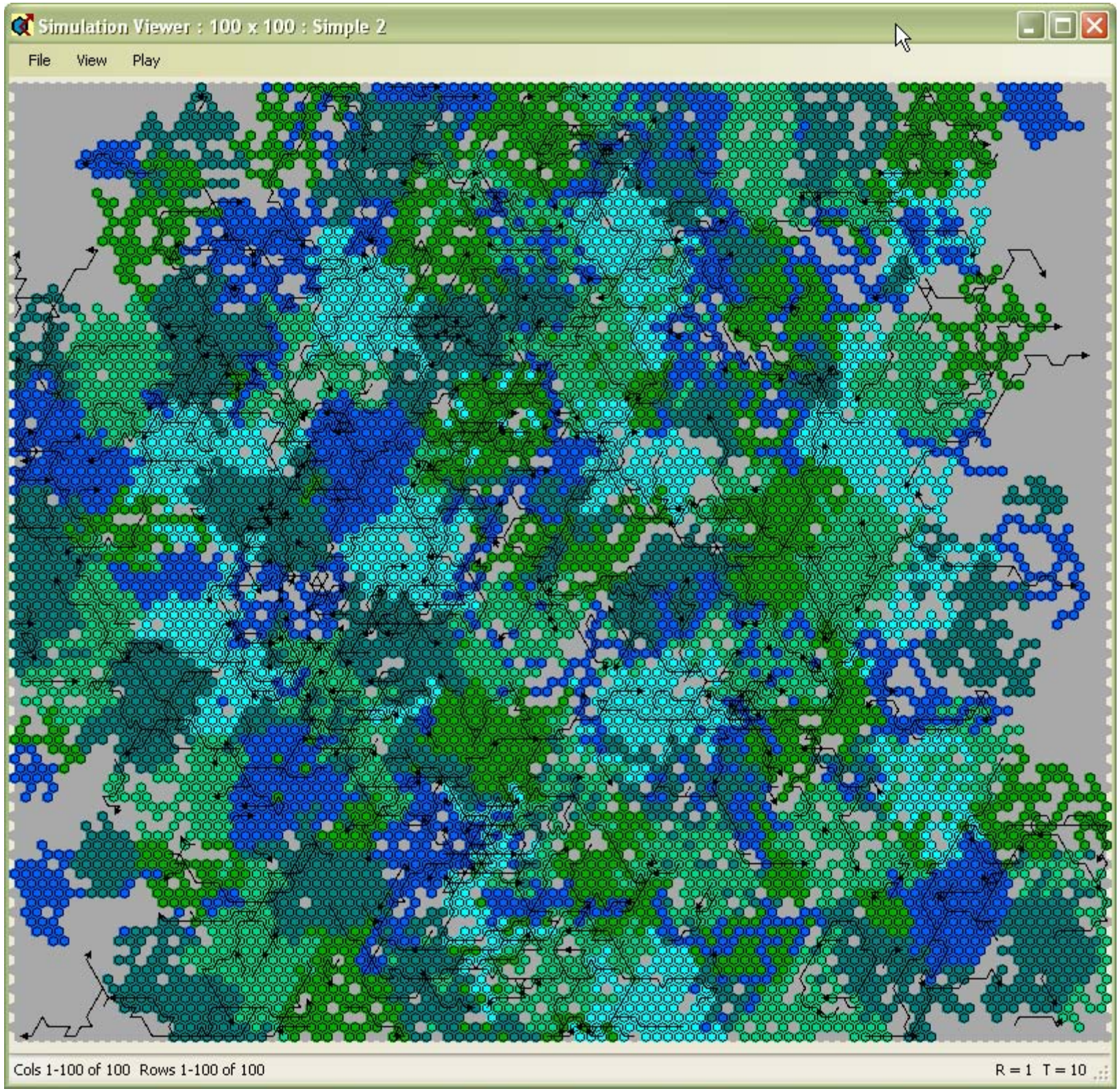

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 5

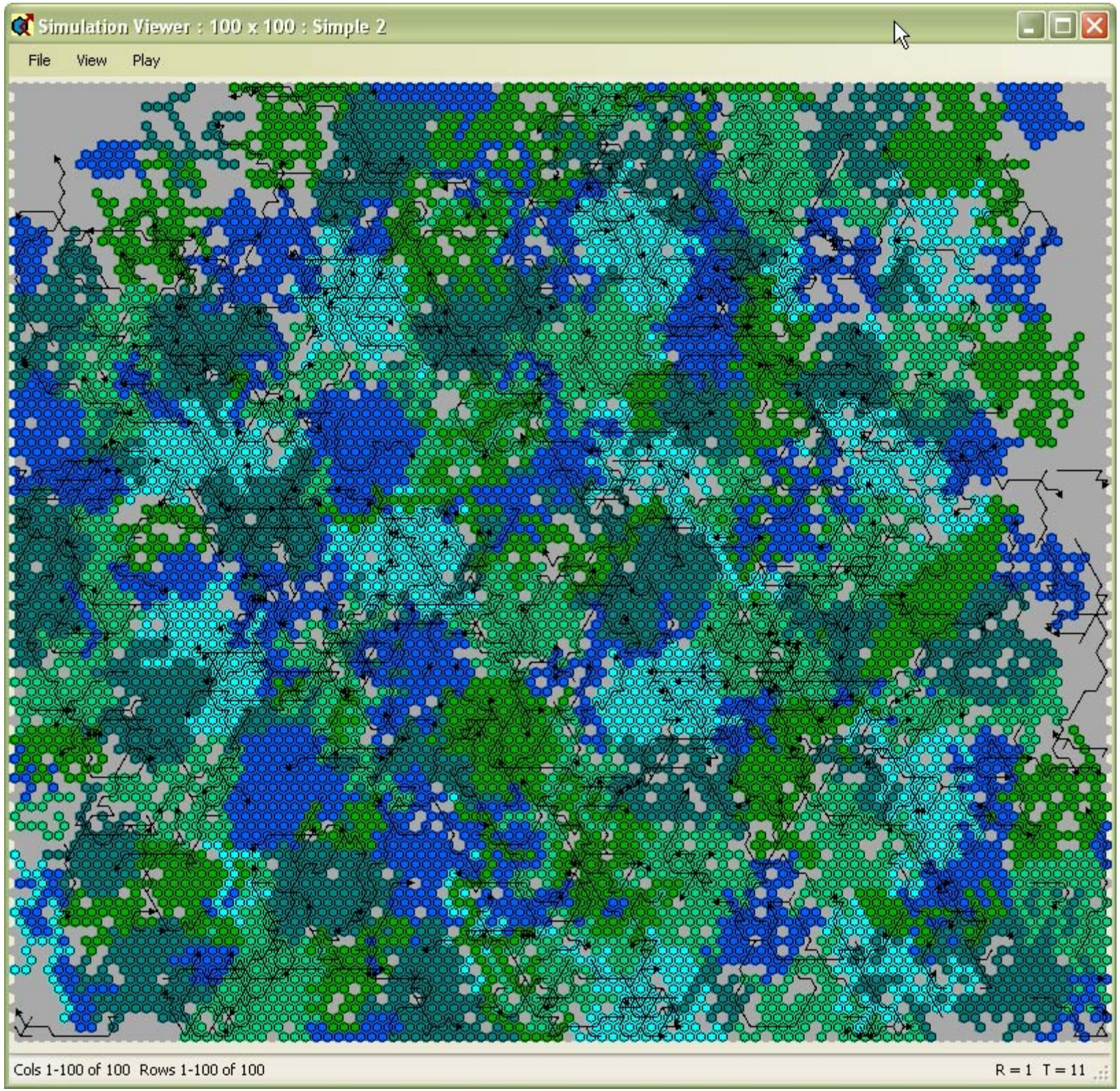

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 6

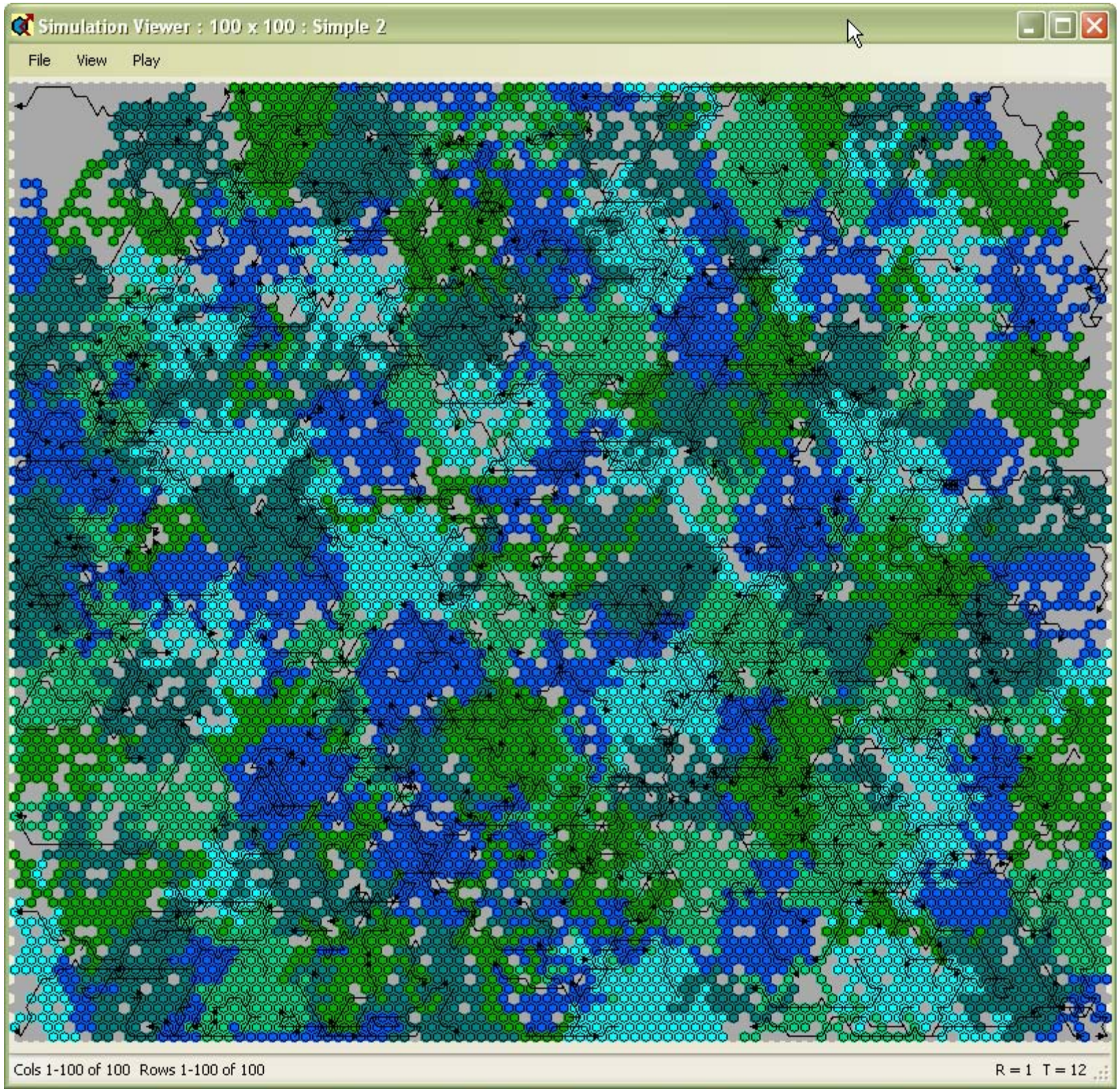

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 7

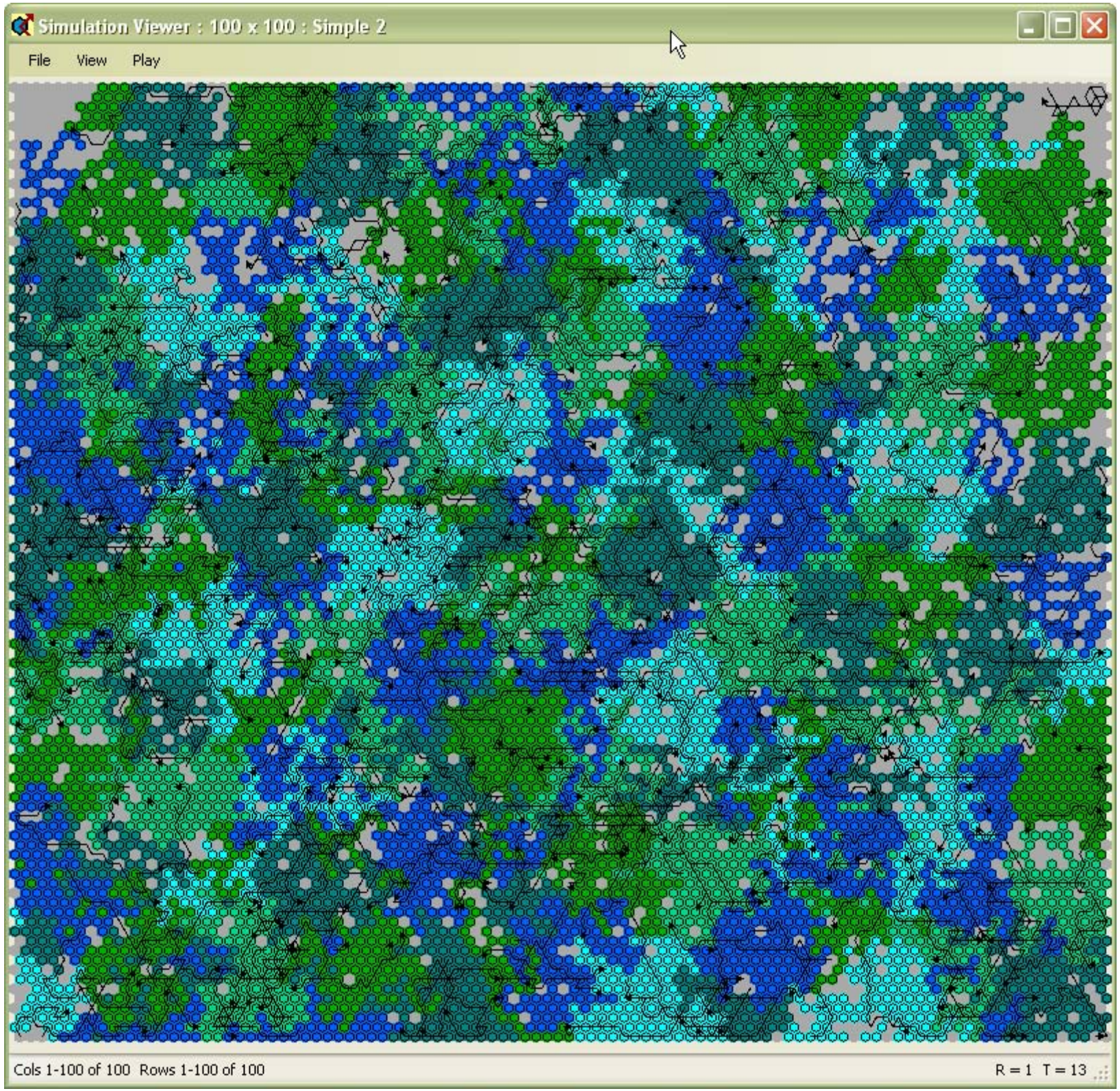

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 8

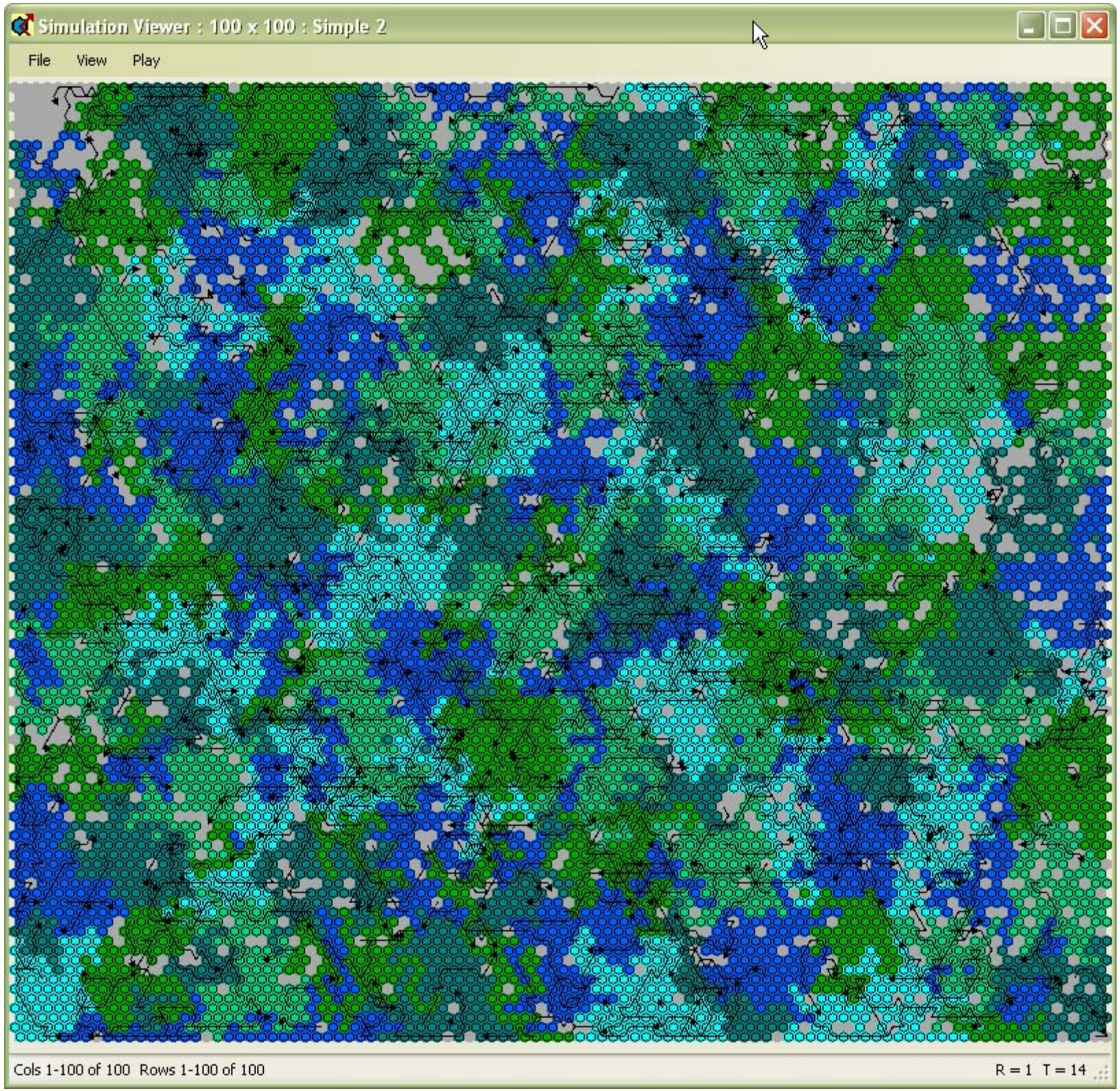

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 9

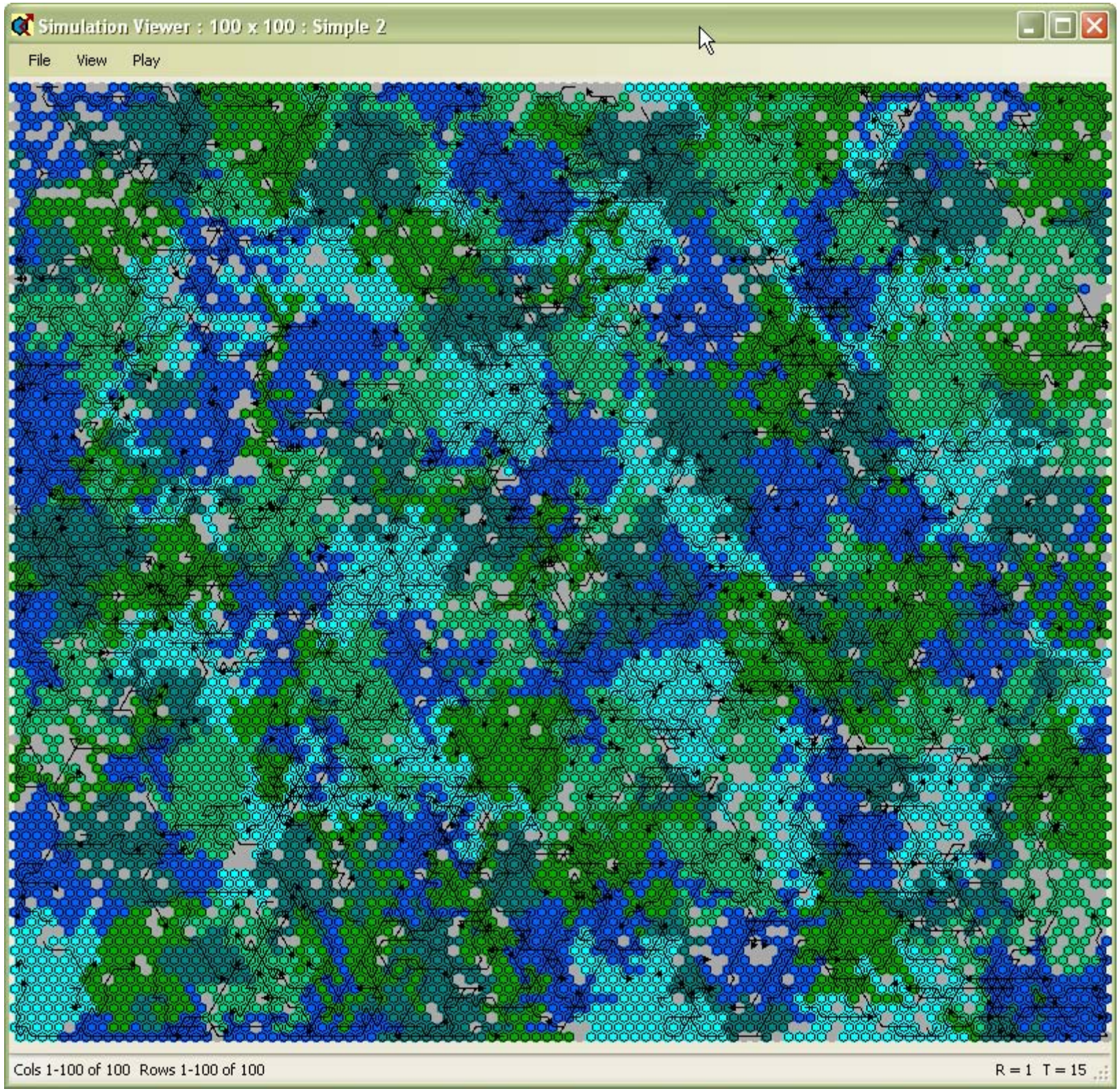

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 10


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 11


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 12


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 13


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 14

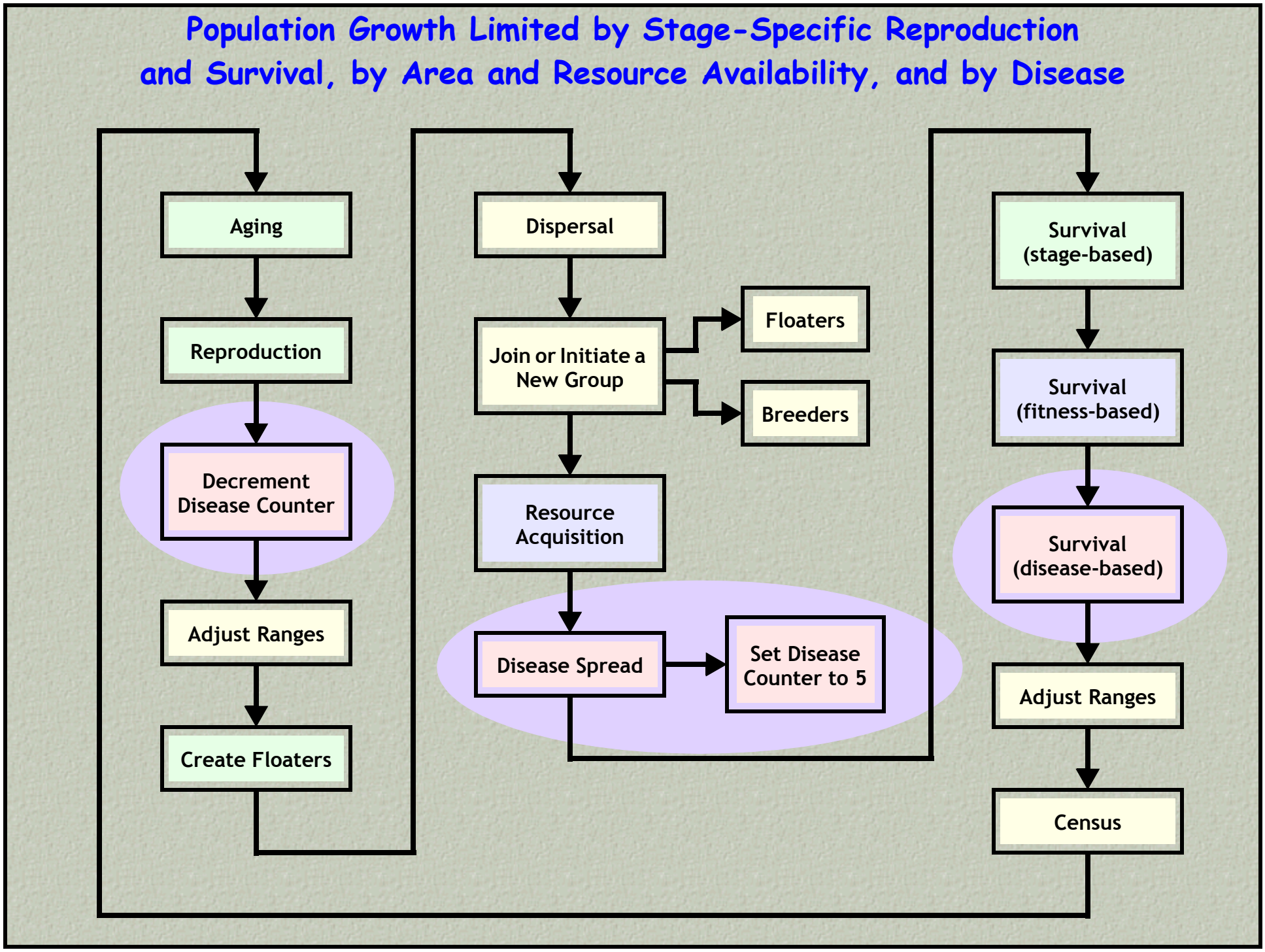

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 15

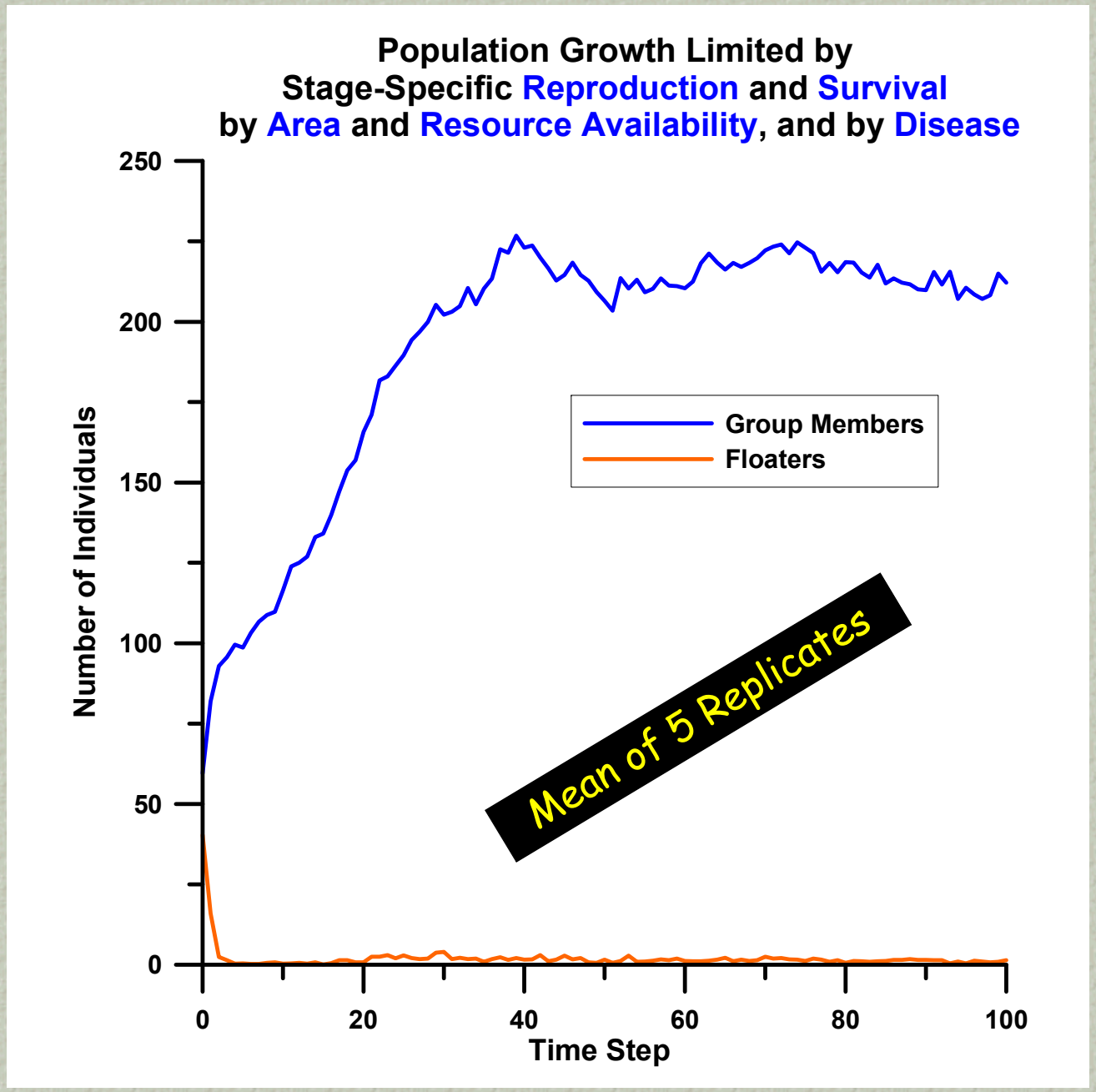
Add A Pseudo-Disease Component

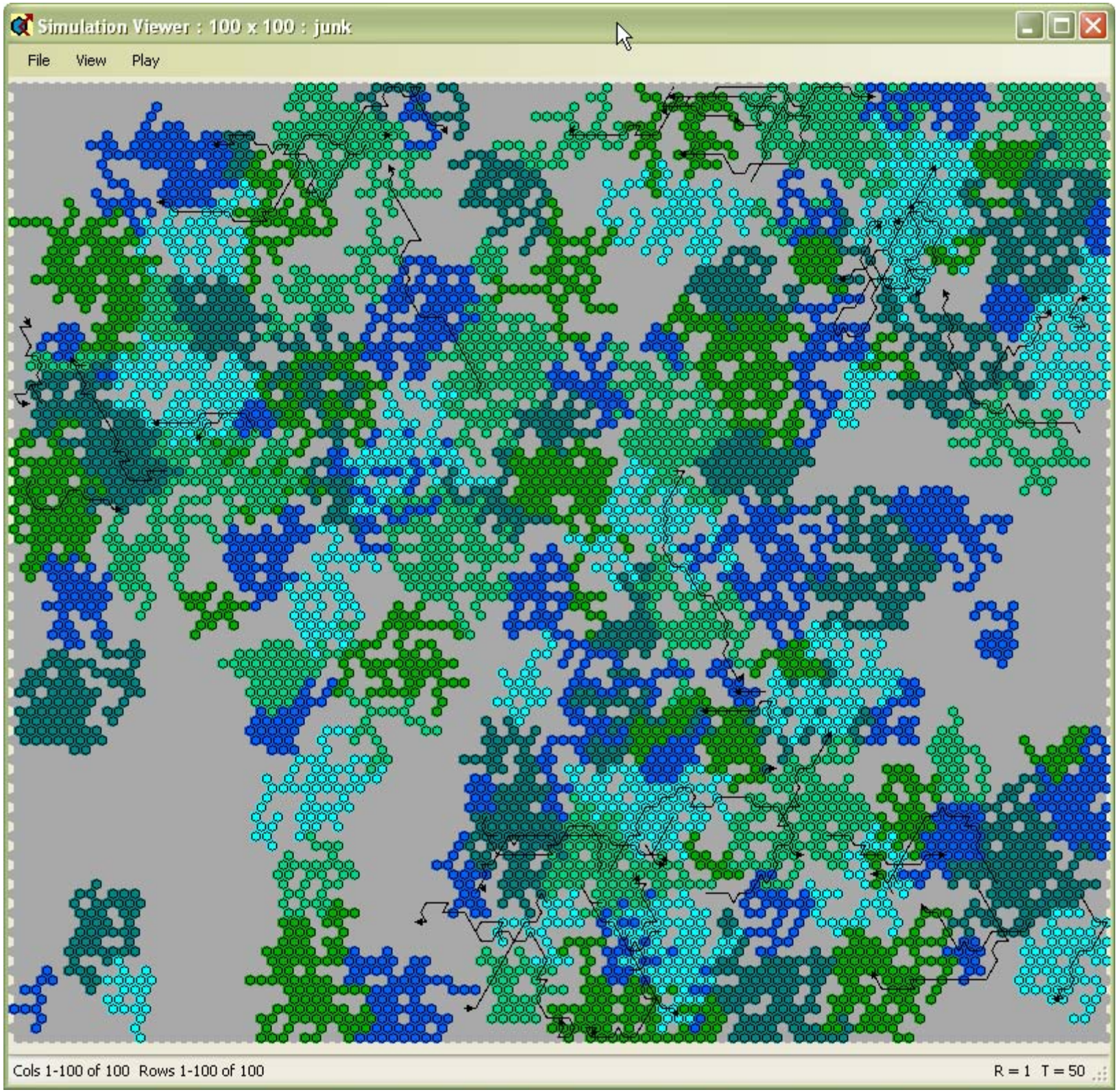
The disease model is over-simplified
It spreads from individual to individual
It takes >= 5 time steps to lose the infection

- The disease counter is decremented each time step
- Individuals are disease-free if the counter = 0
- The disease counter is set to 5 on exposure
- The disease is spread by birth and by contact

Population Growth Limited by Stage-Specific Reproduction and Survival, by Area and Resource Availability, and by Disease



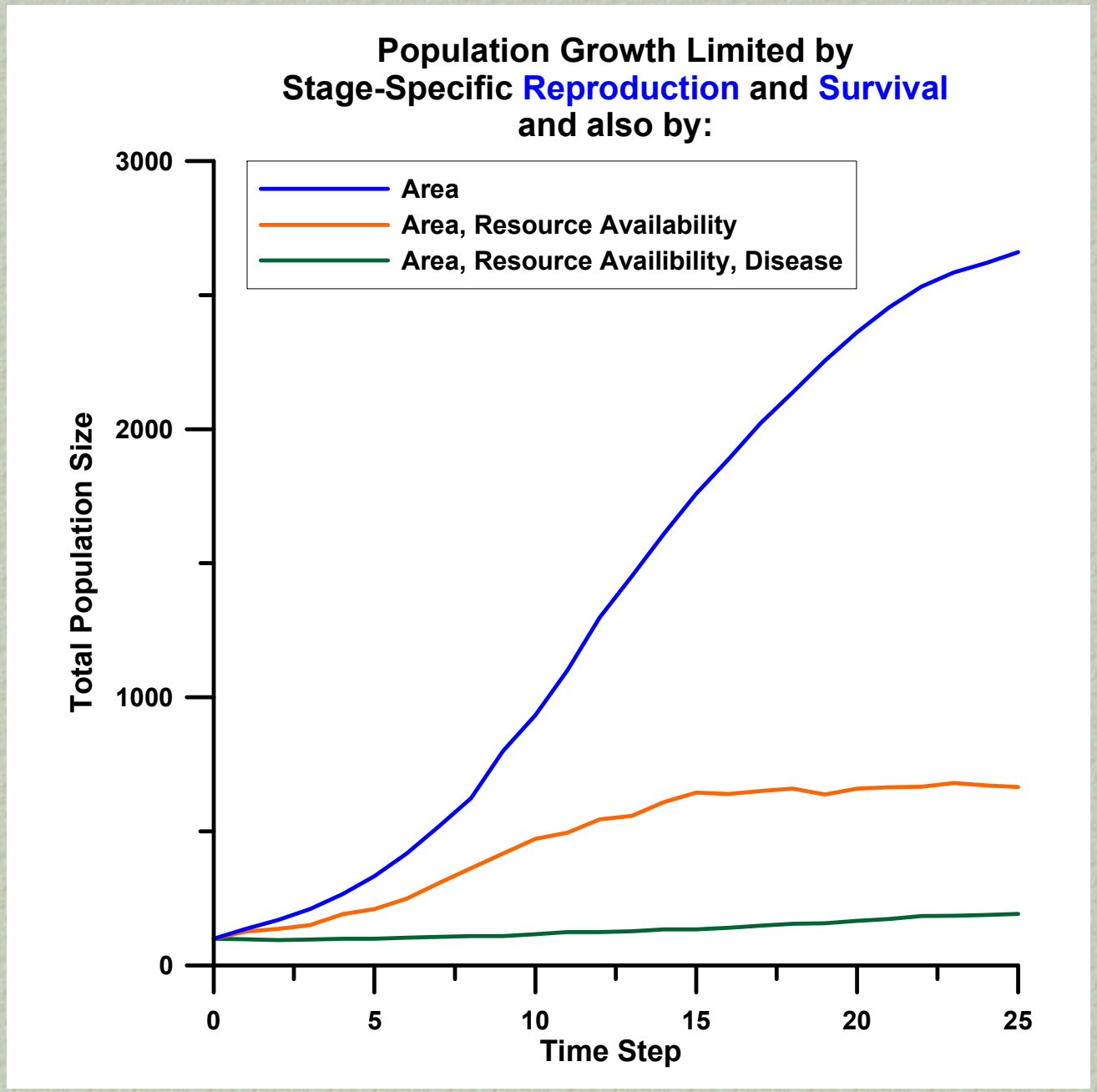

Population Growth Limited by
Stage-Specific Reproduction and Survival
by Area and Resource Availability, and by Disease
Number of Individuals
250
200
150
100
50
0
0
20
40
60
80
100
Time Step
Group Members
Floaters
Mean of 5 Replicates


Simulation Viewer : 100 x 100 : junk
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 50

Quick Recap

We have compared four model structures:
Population growth limited by:

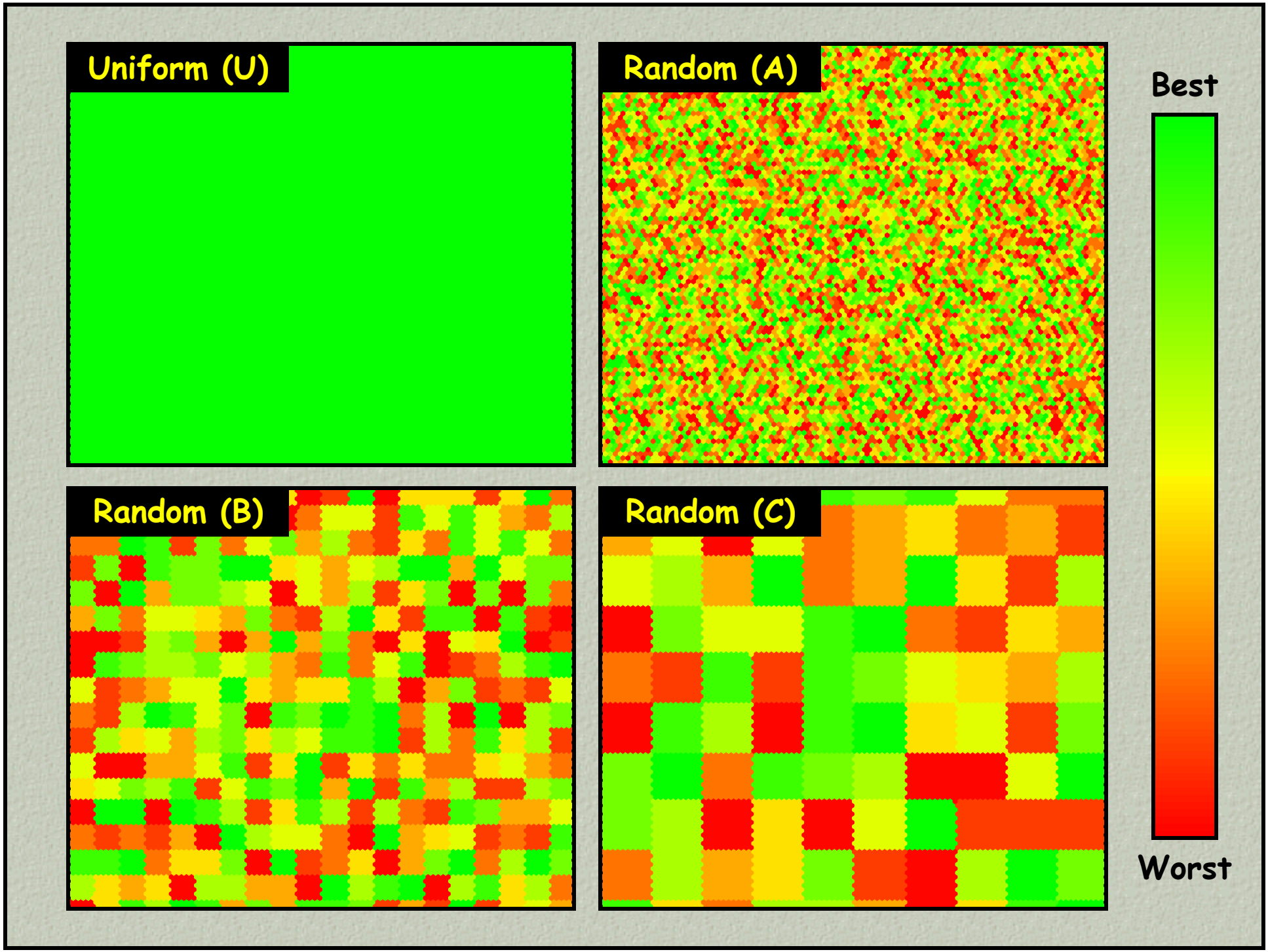
- Stage-specific survival and reproduction
- Plus area (space is limited)
- Plus resources (resource availability is limited)
- Plus disease (which can impact survival rates)

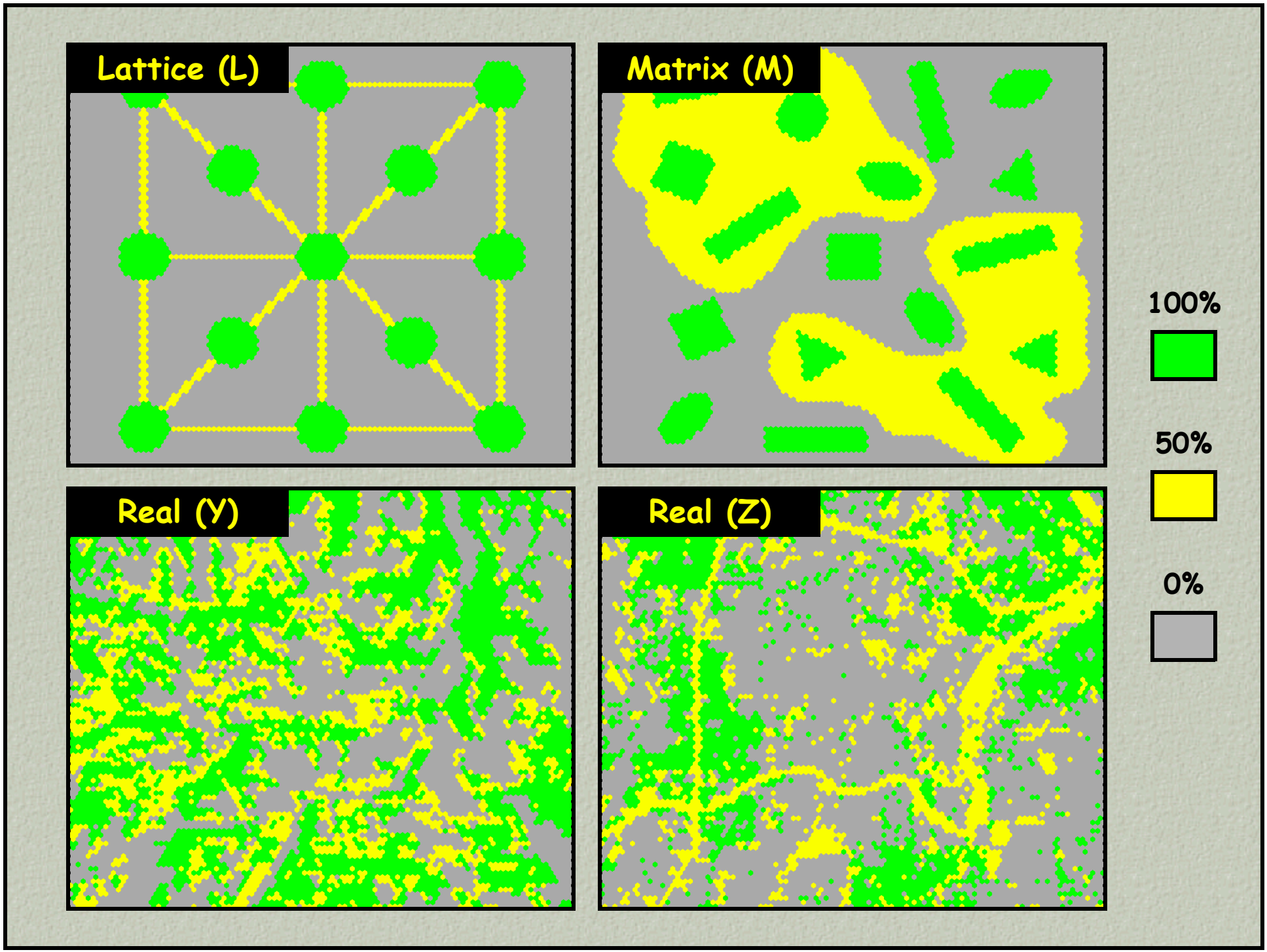

Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by:
Area
Area, Resource Availability
Area, Resource Availibility, Disease
Total Population Size
3000
2000
1000
0
0
5
10
15
20
25
Time Step

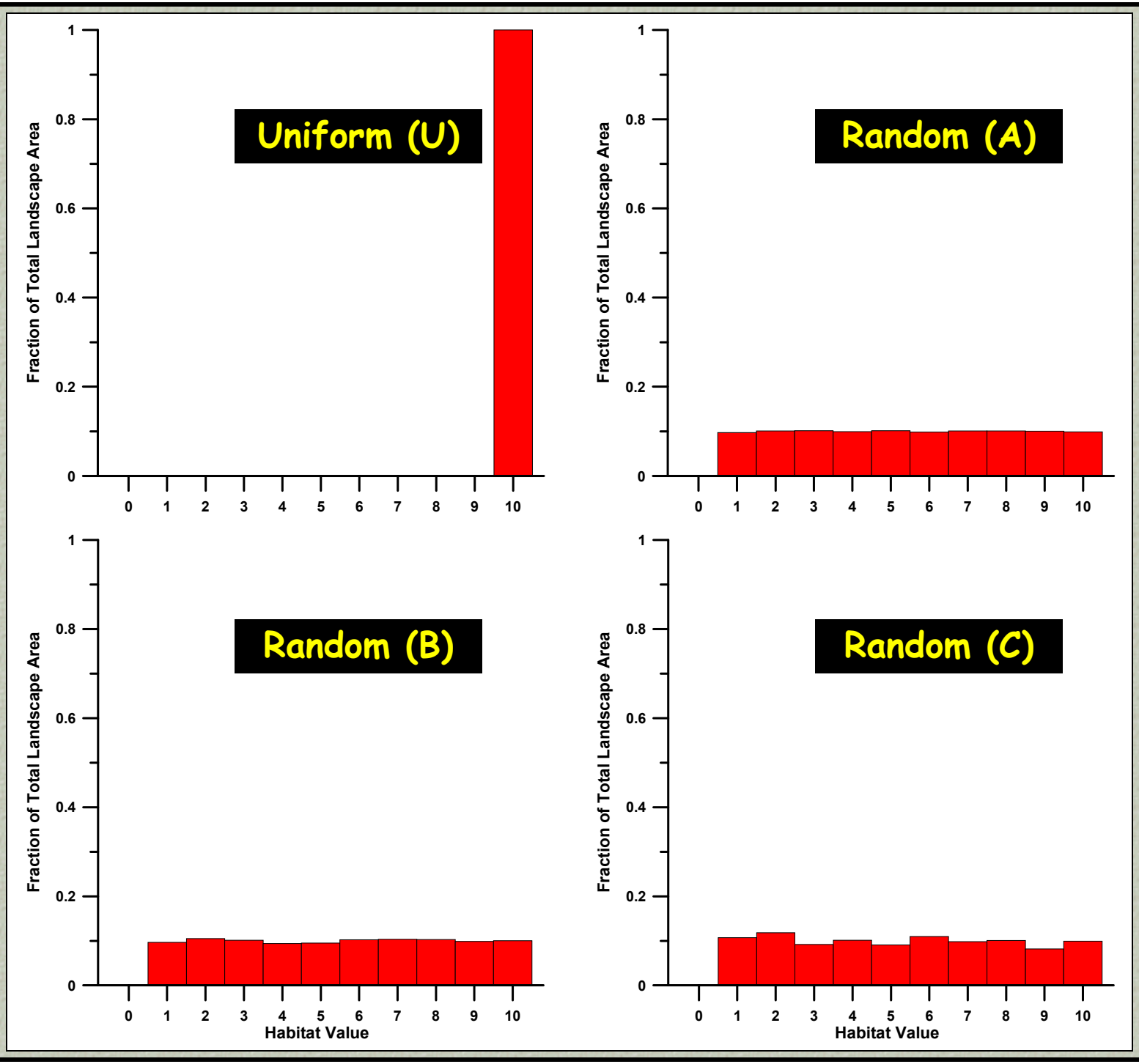
Now On To Spatial Structure

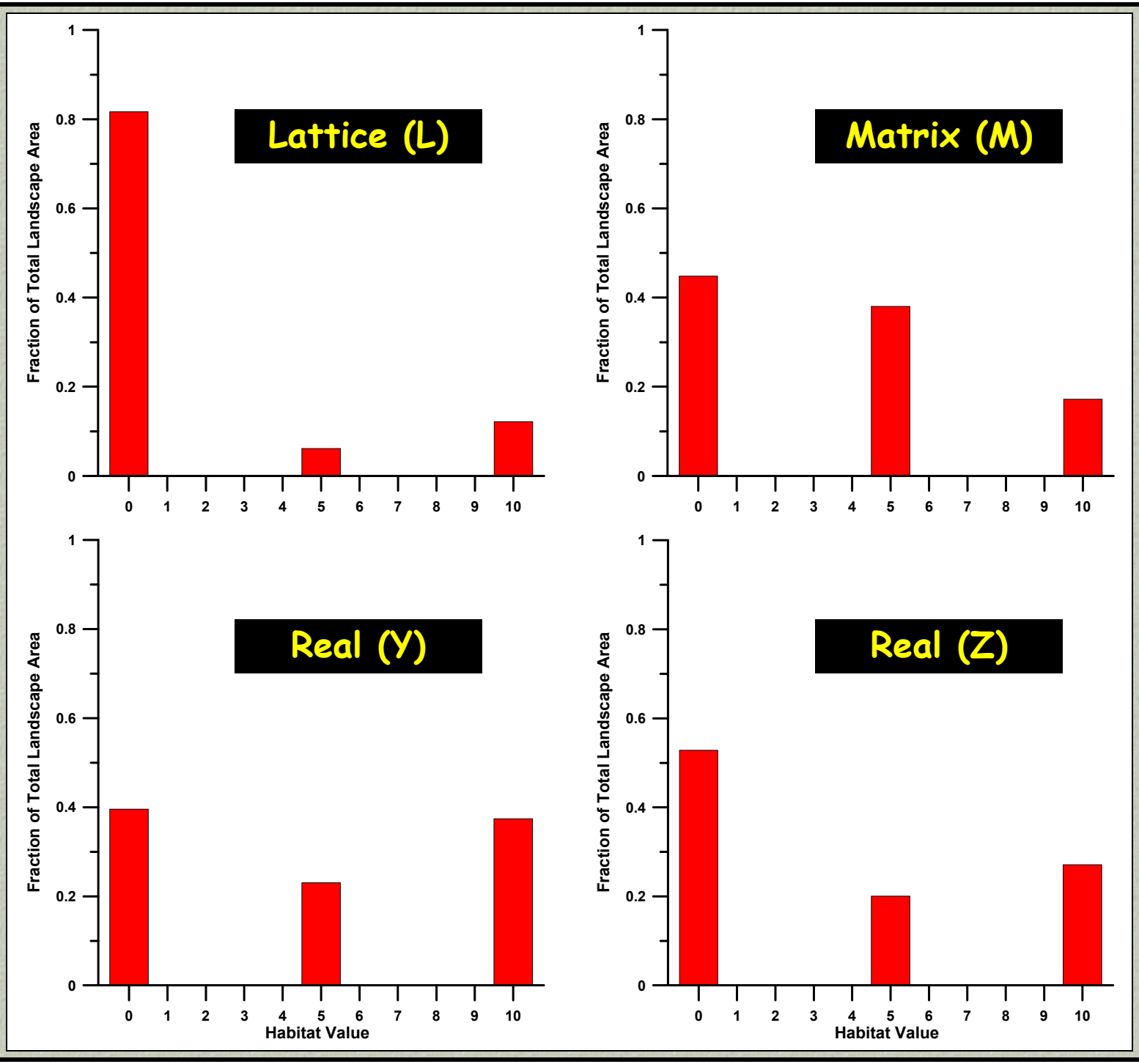
All of the previous results were generated
in a 100 x 100 hexagon landscape made up
of exclusively perfect quality habitat

- Habitat quality may vary from useless to ideal
- The quality spectrum may be more or less continuous
- Landscape structure may be simple or complex


Uniform (U)
Random (A)
Random (B)
Random (C)
Best
Worst


Lattice (L)
Matrix (M)
Real (Y)
Real (Z)
100%
50%
0%


Uniform (U)
Random (A)
Random (B)
Random (C)
Fraction of Total Landscape Area
Habitat Value
0
0.2
0.4
0.6
0.8
1
0 1 2 3 4 5 6 7 8 9 10

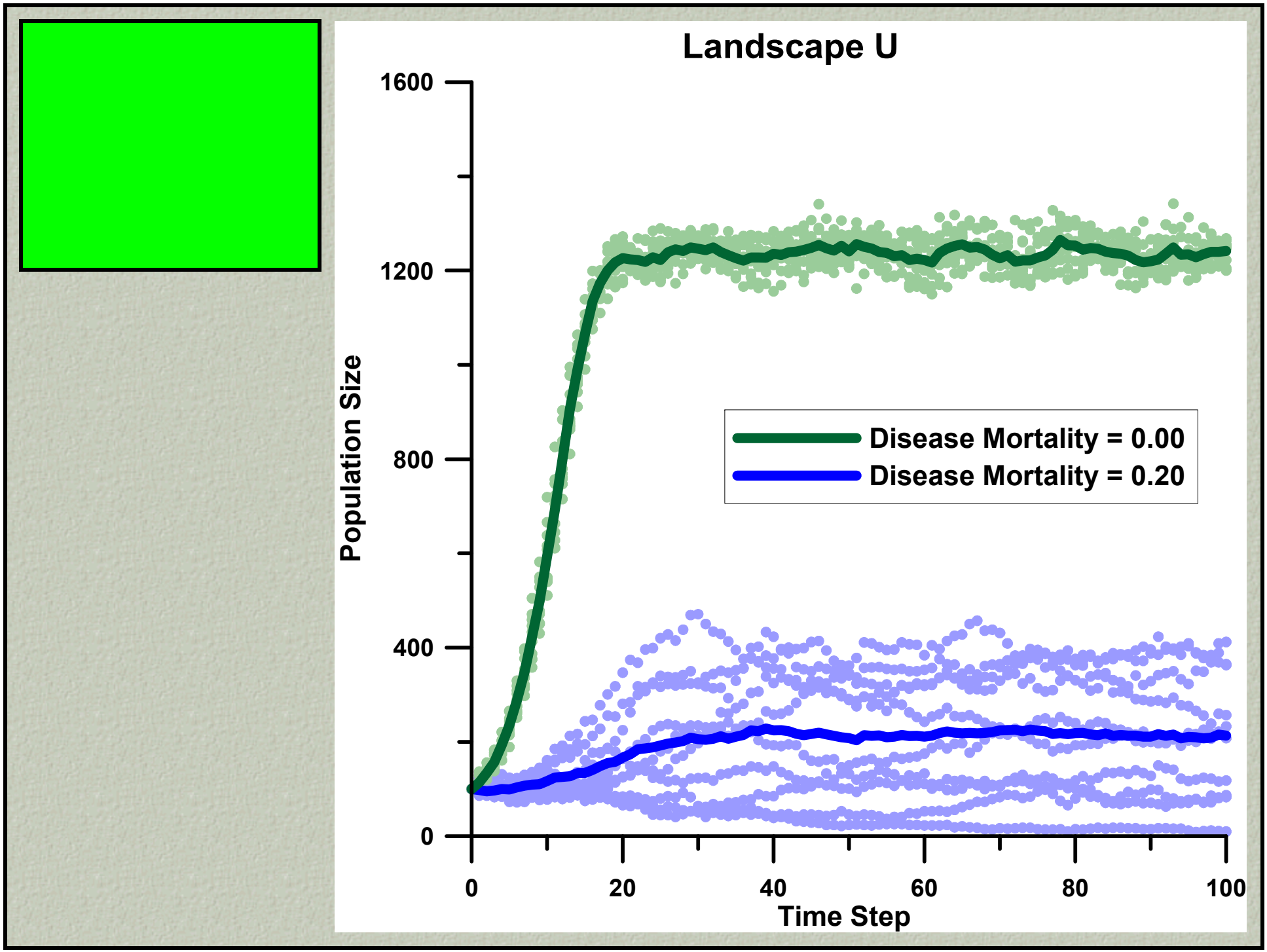

Lattice (L)
Matrix (M)
Real (Y)
Real (Z)
Fraction of Total Landscape Area
Habitat Value
0
0.2
0.4
0.6
0.8
1
0 1 2 3 4 5 6 7 8 9 10

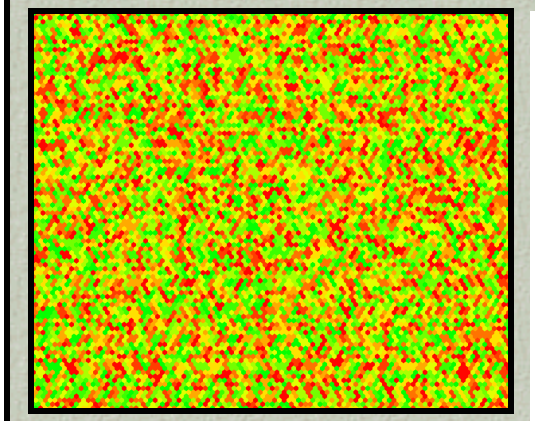
A Series Of Landscape Comparisons

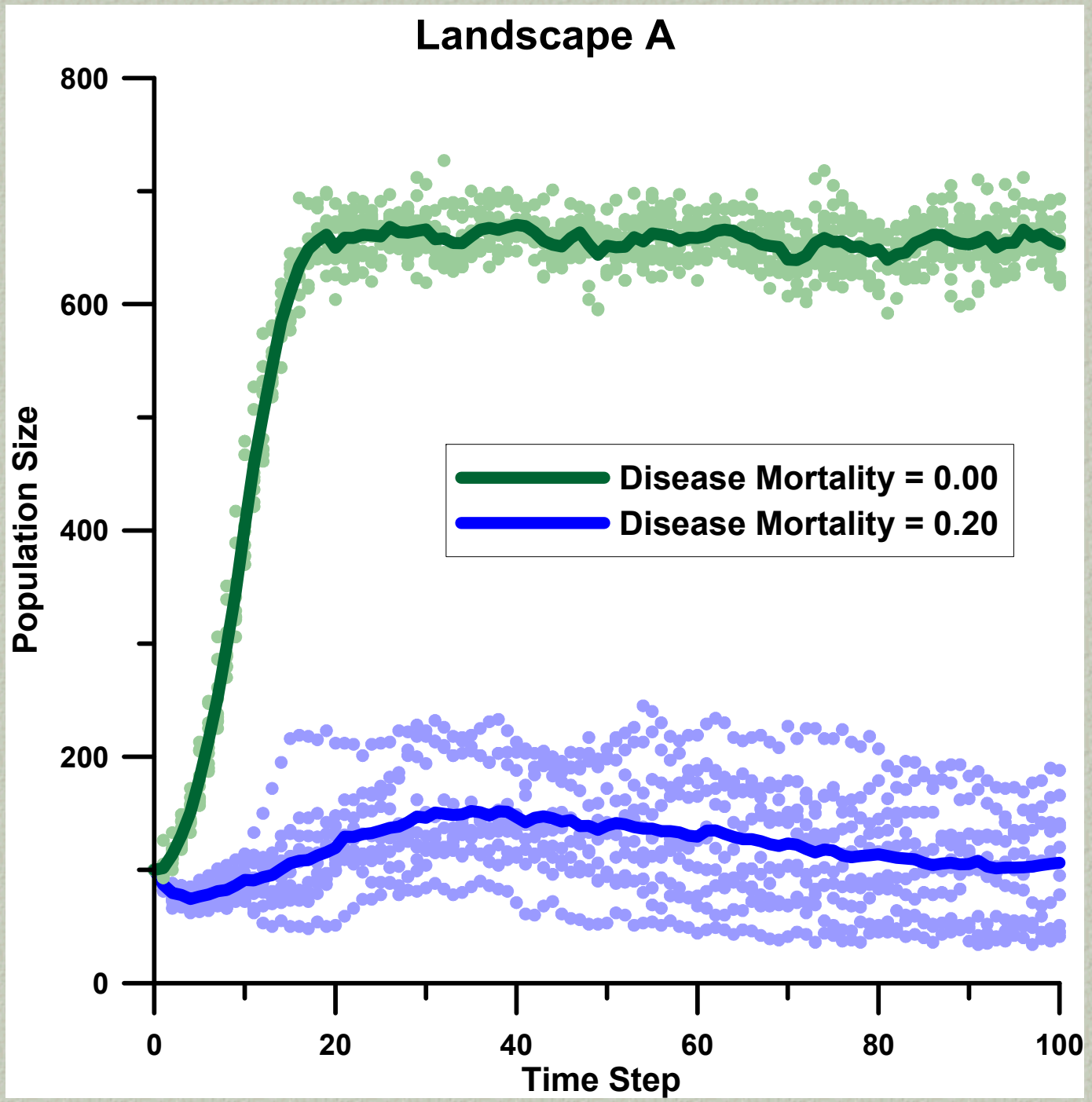
➔ **Population Size** ←

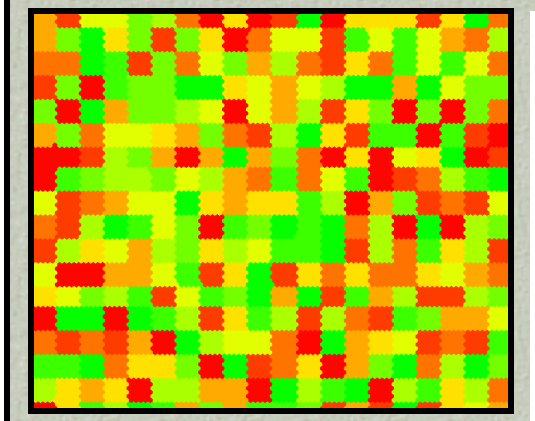
Each simulation consists of 5 replicates
of 100 time steps (years)
Means, and variability are illustrated

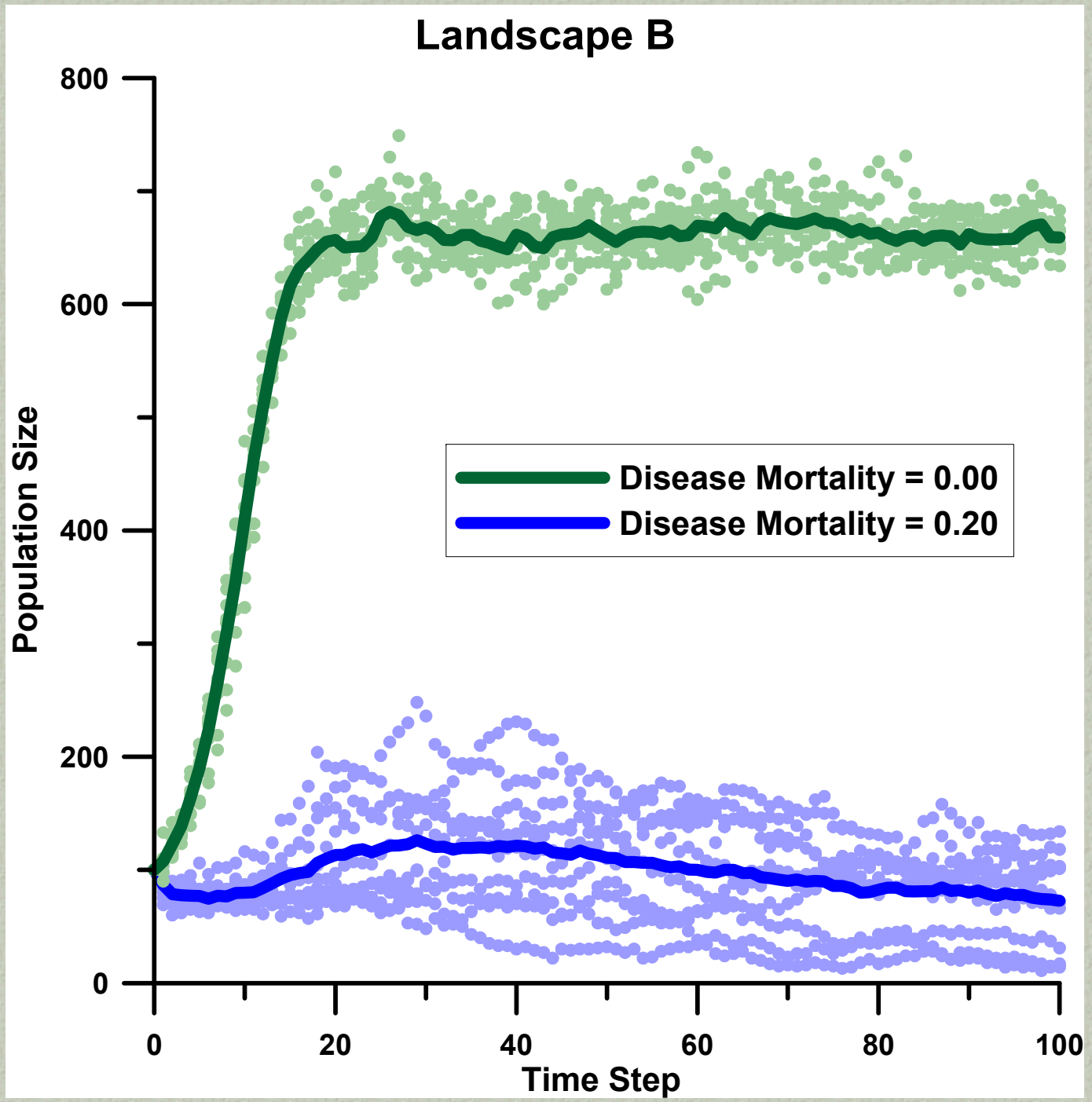
For each landscape, a simulation was run with
Disease mortality = 0%
Disease mortality = 20%

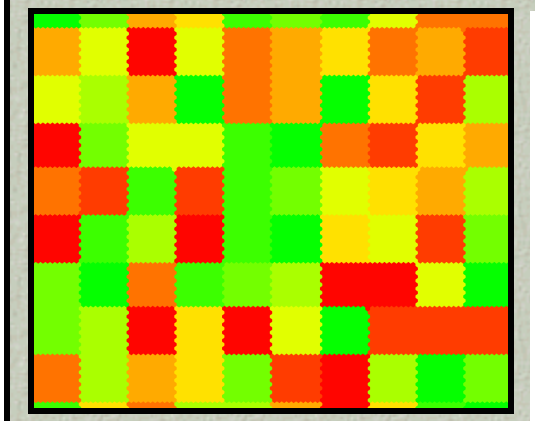

Landscape U
1600
1200
800
400
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

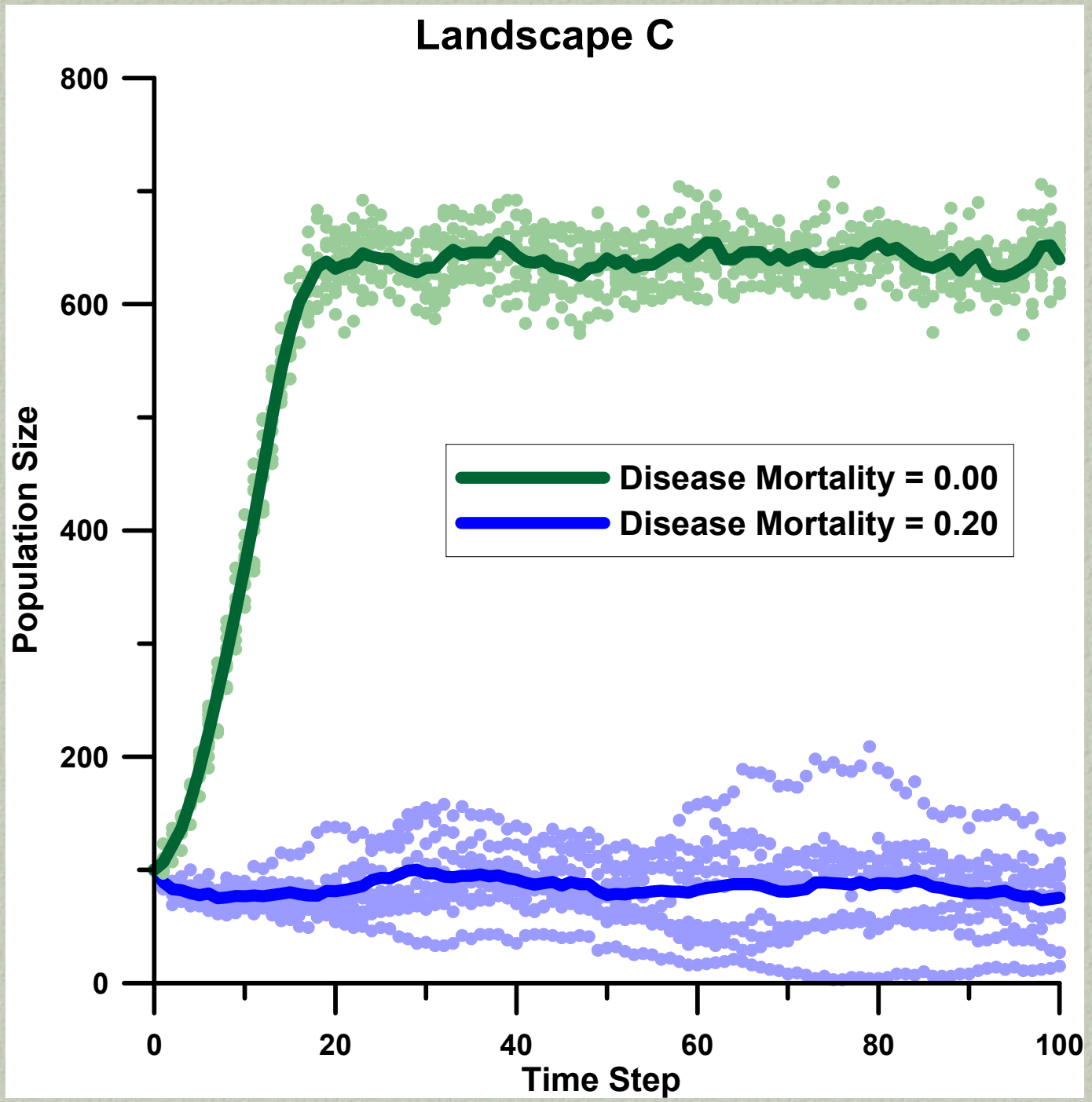


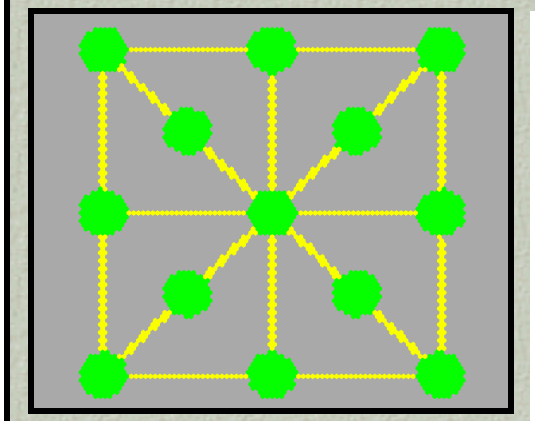

Landscape A
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

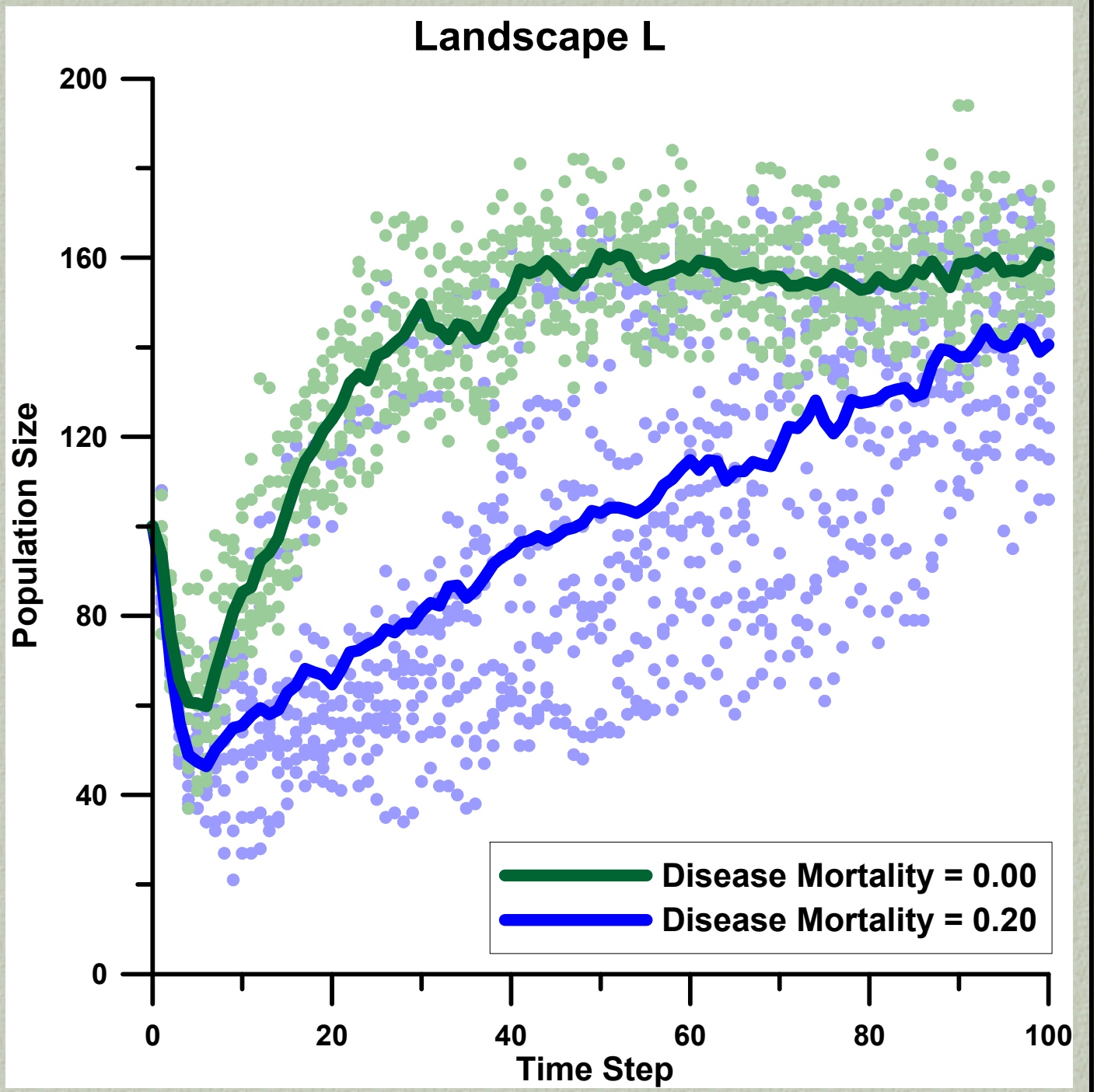


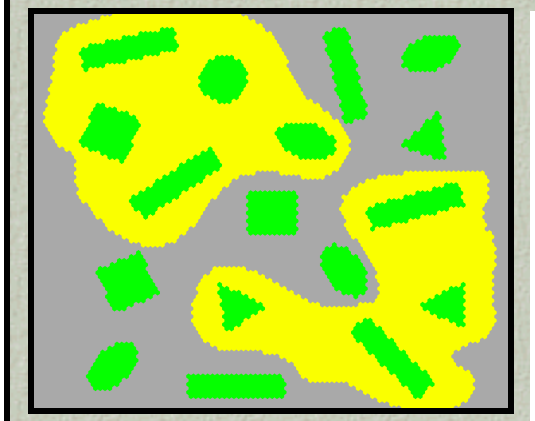

Landscape B
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

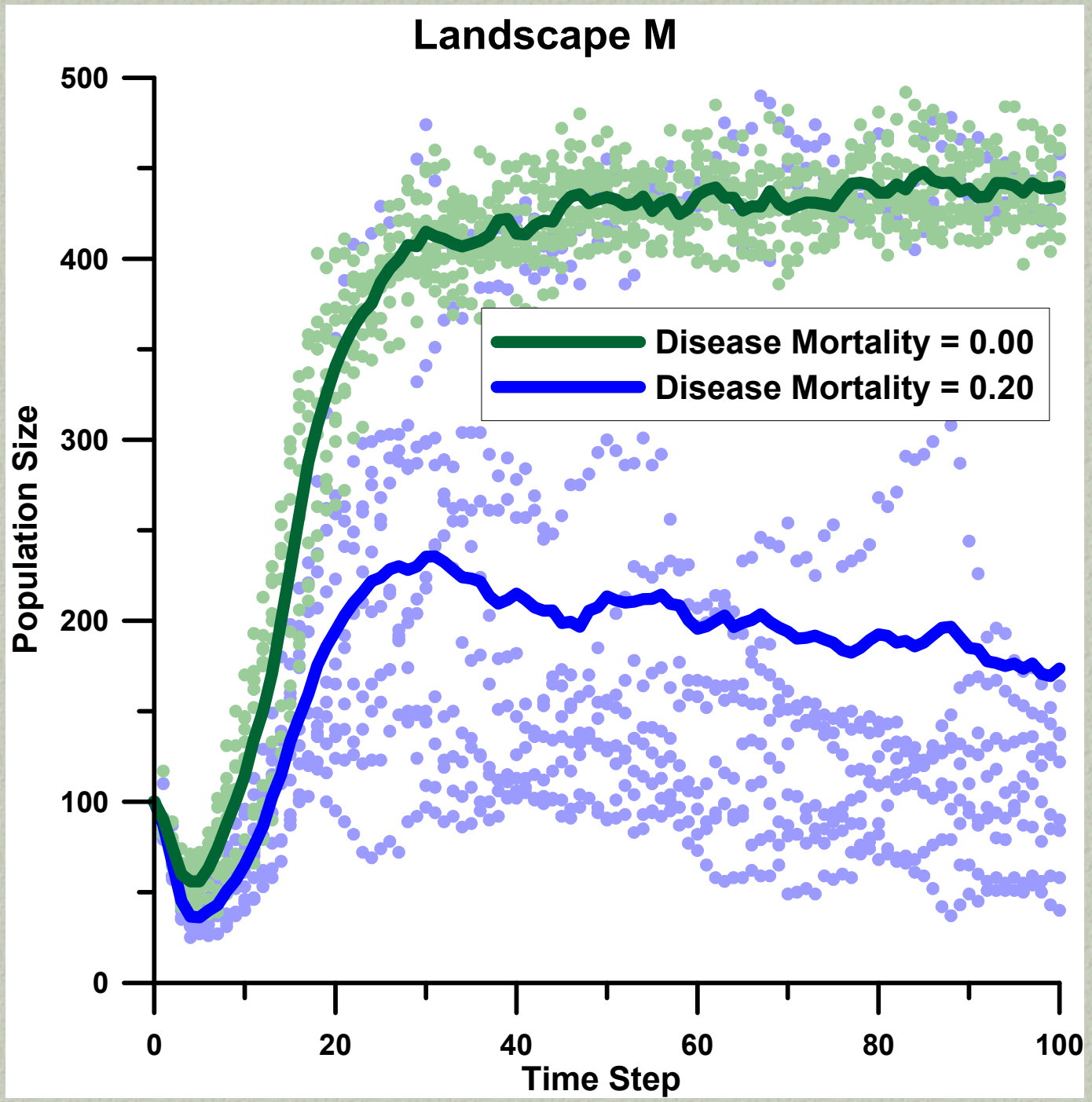


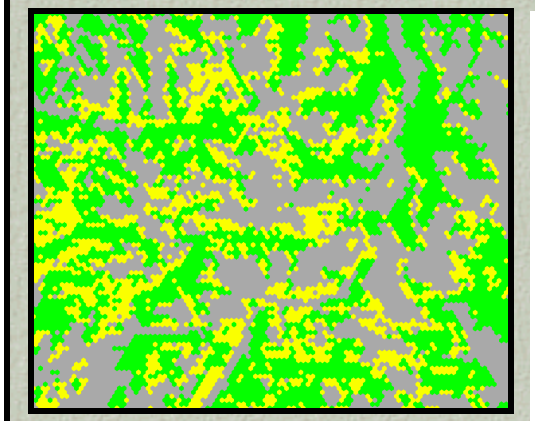

Landscape C
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

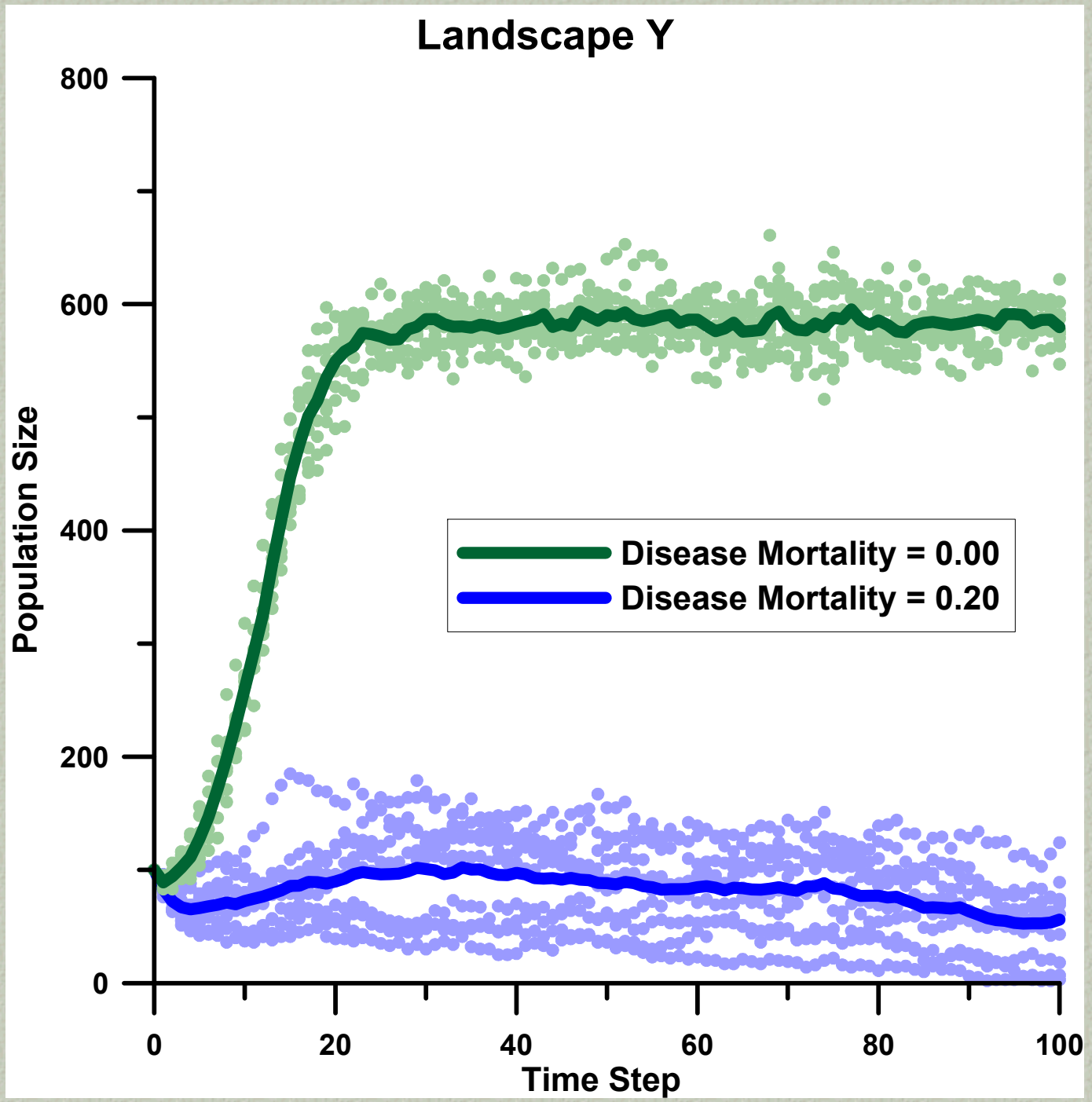


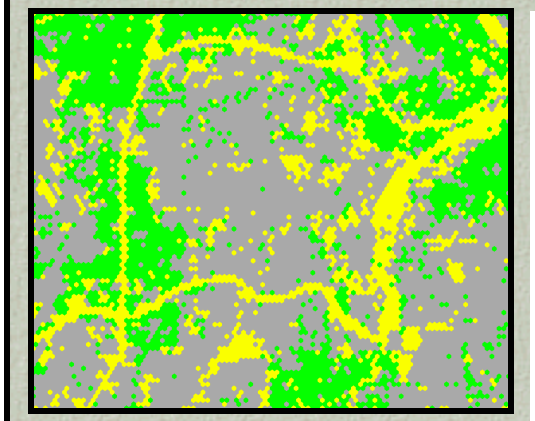

Landscape L
Population Size
200
160
120
80
40
0
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

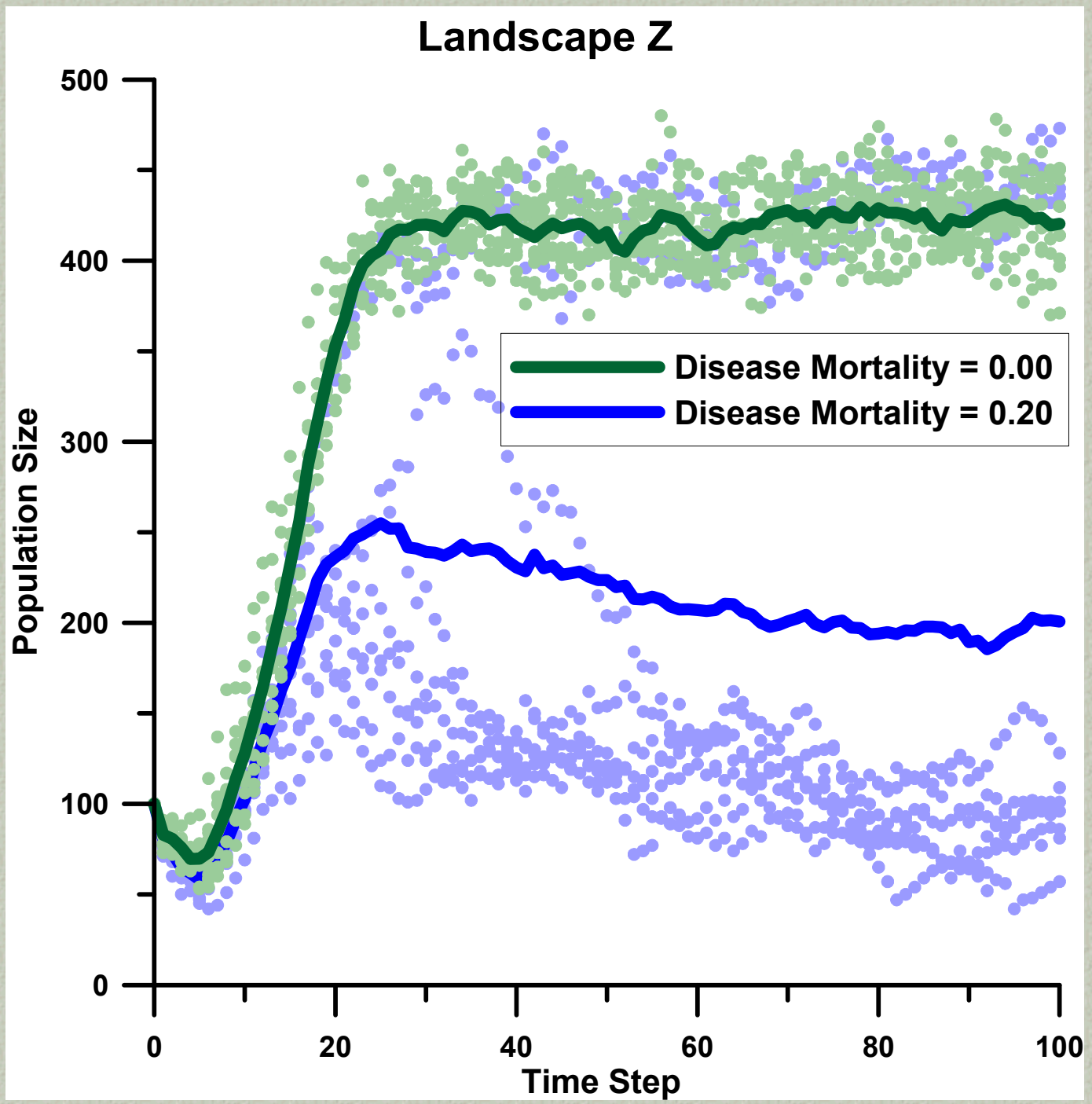



Landscape M
Population Size
500
400
300
200
100
0
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20




Landscape Y
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20



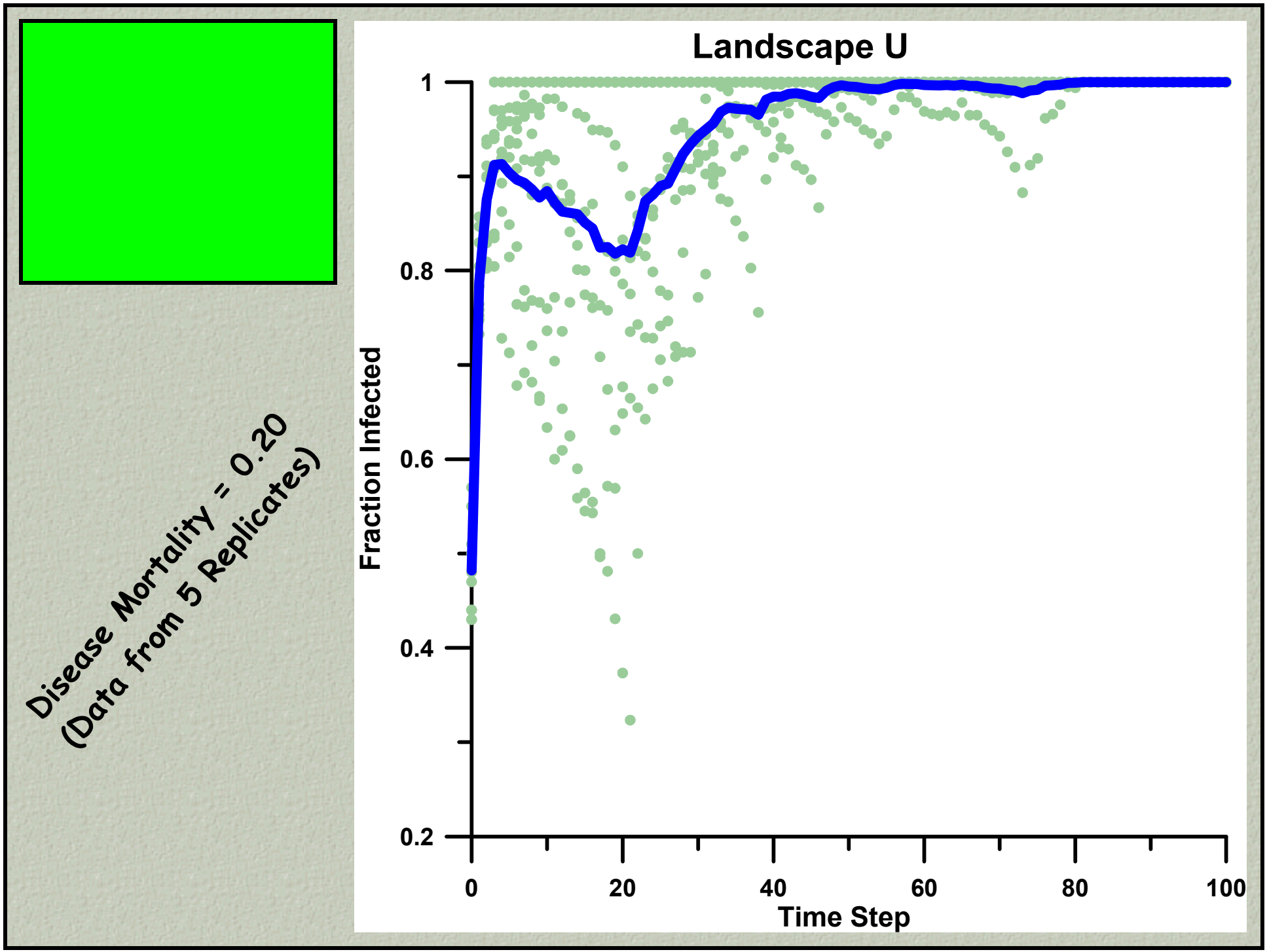

Landscape Z
Population Size
Time Step
0
100
200
300
400
500
0
20
40
60
80
100
Disease Mortality = 0.00
Disease Mortality = 0.20

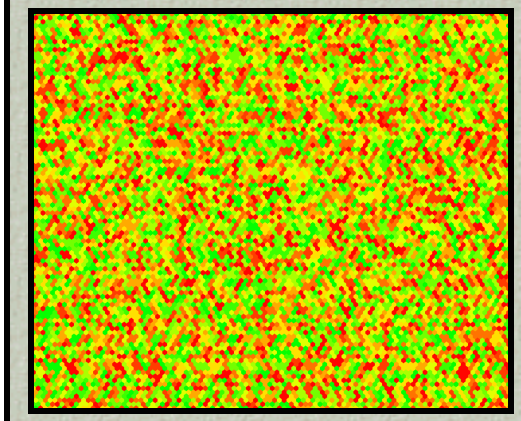
A Series Of Landscape Comparisons

➔ **Percent Infected** ←

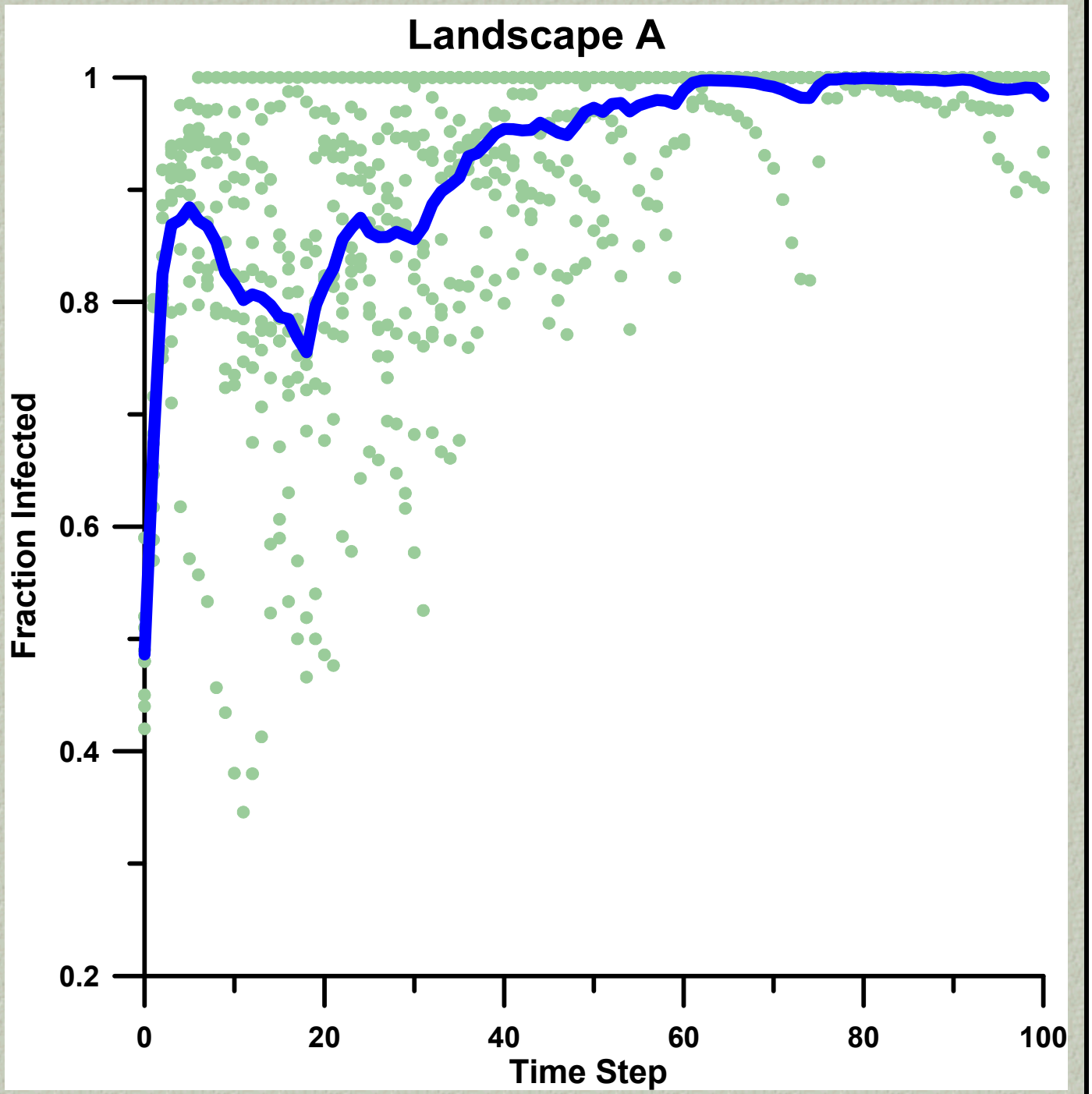
Each simulation consists of 5 replicates
of 100 time steps (years)
Means, and variability are illustrated

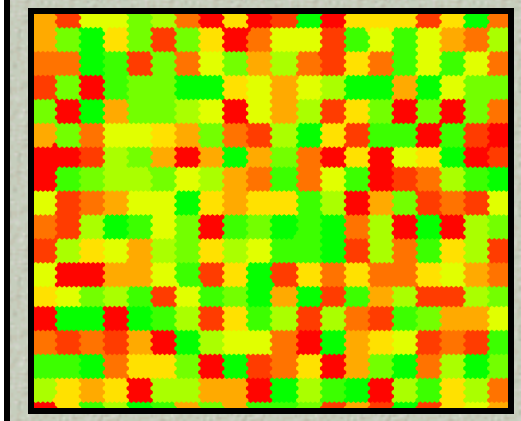
For each landscape, a simulation was run with
Disease mortality = 20% only


Landscape U
Fraction Infected
1
0.8
0.6
0.4
0.2
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)

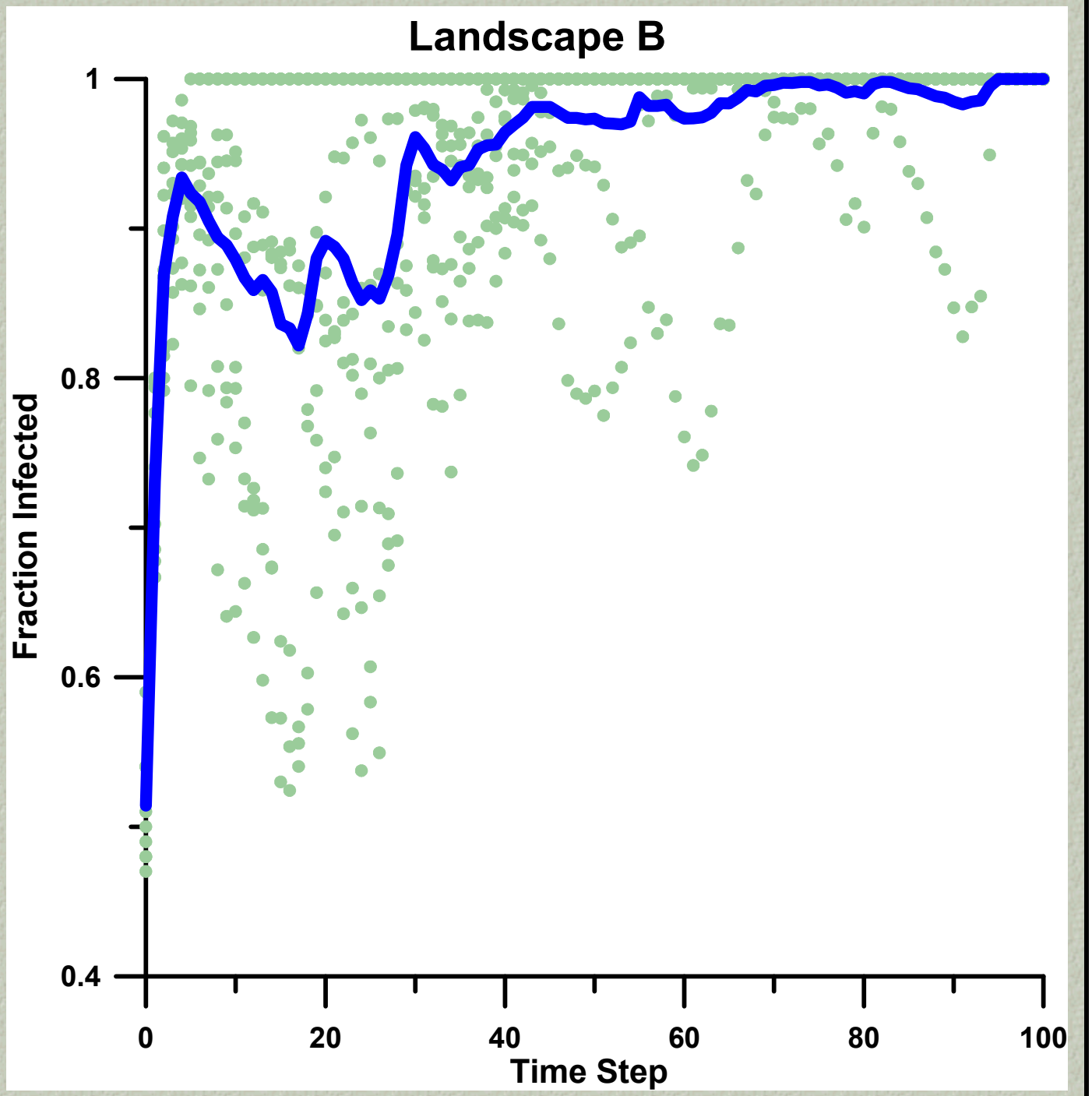


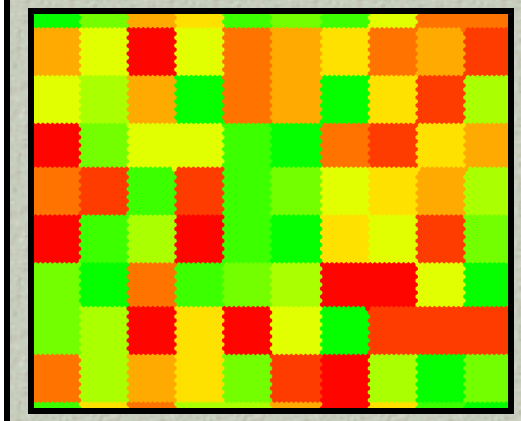
Disease Mortality = 0.20
(Data from 5 Replicates)



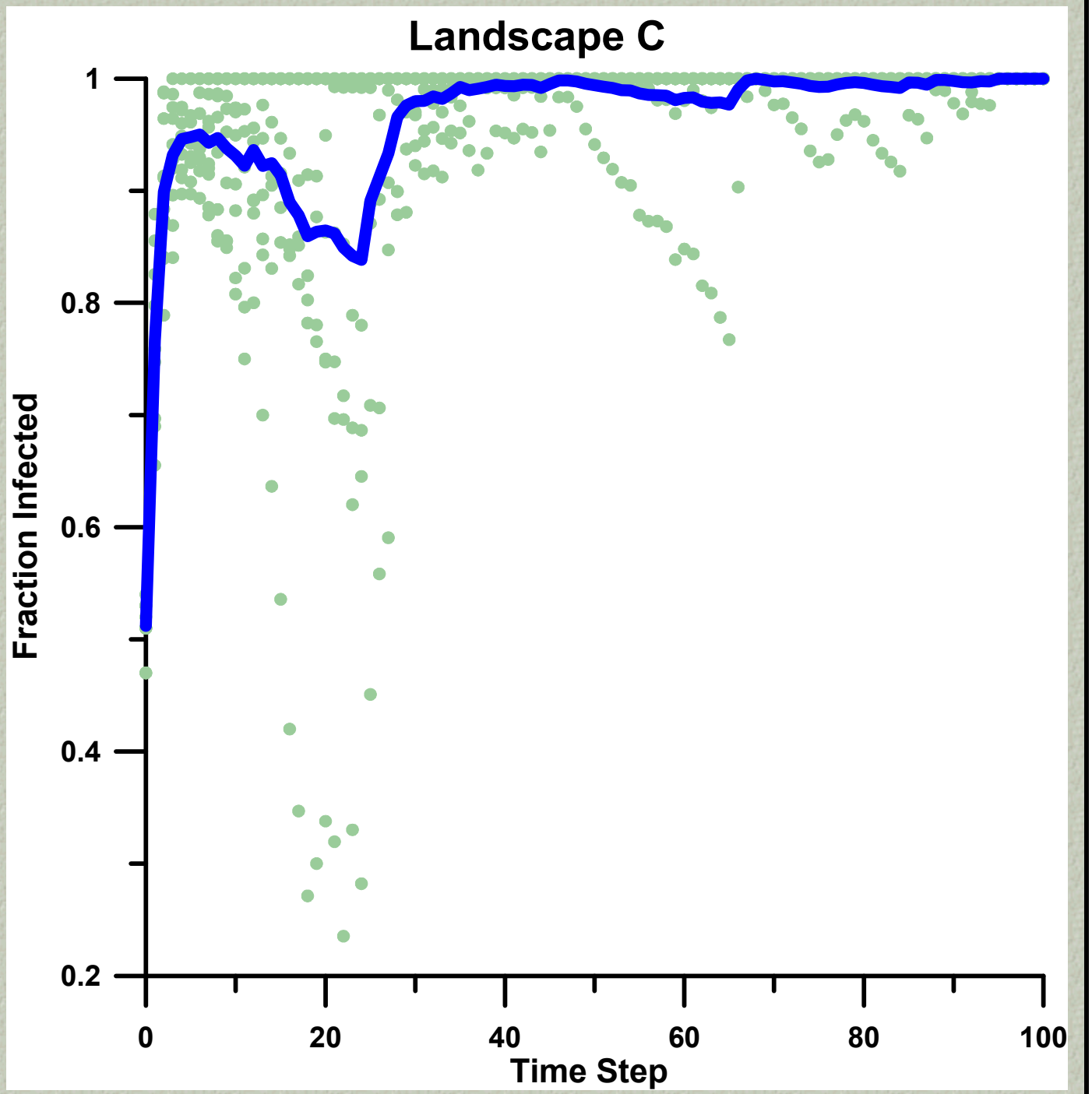


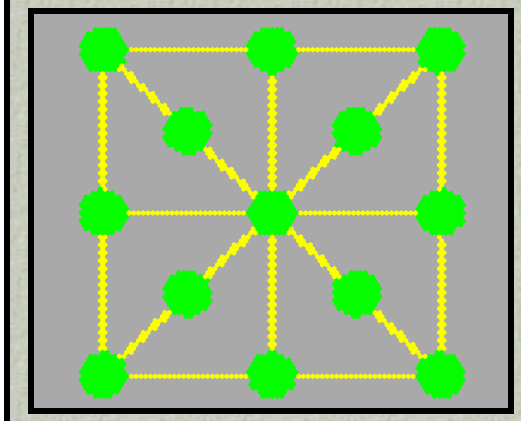
Disease Mortality = 0.20
(Data from 5 Replicates)



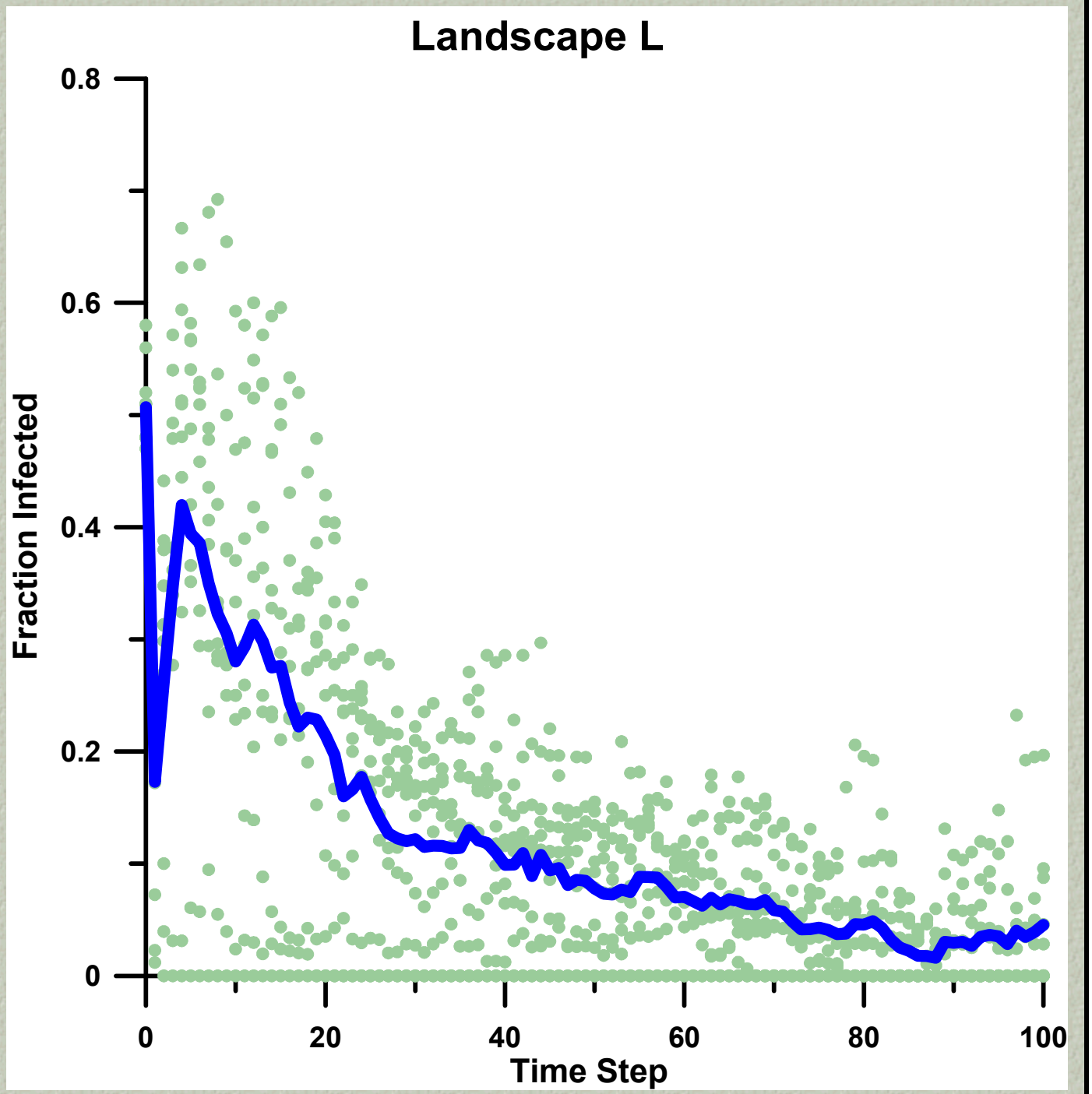


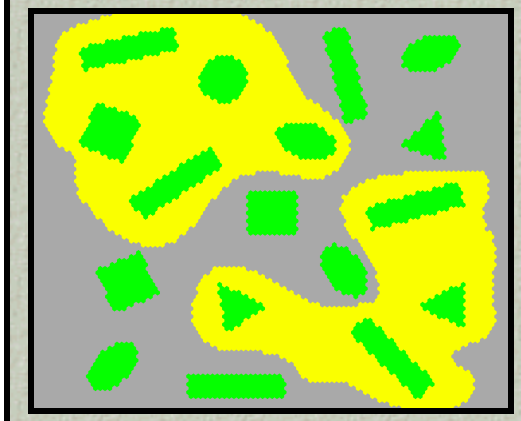
Disease Mortality = 0.20
(Data from 5 Replicates)



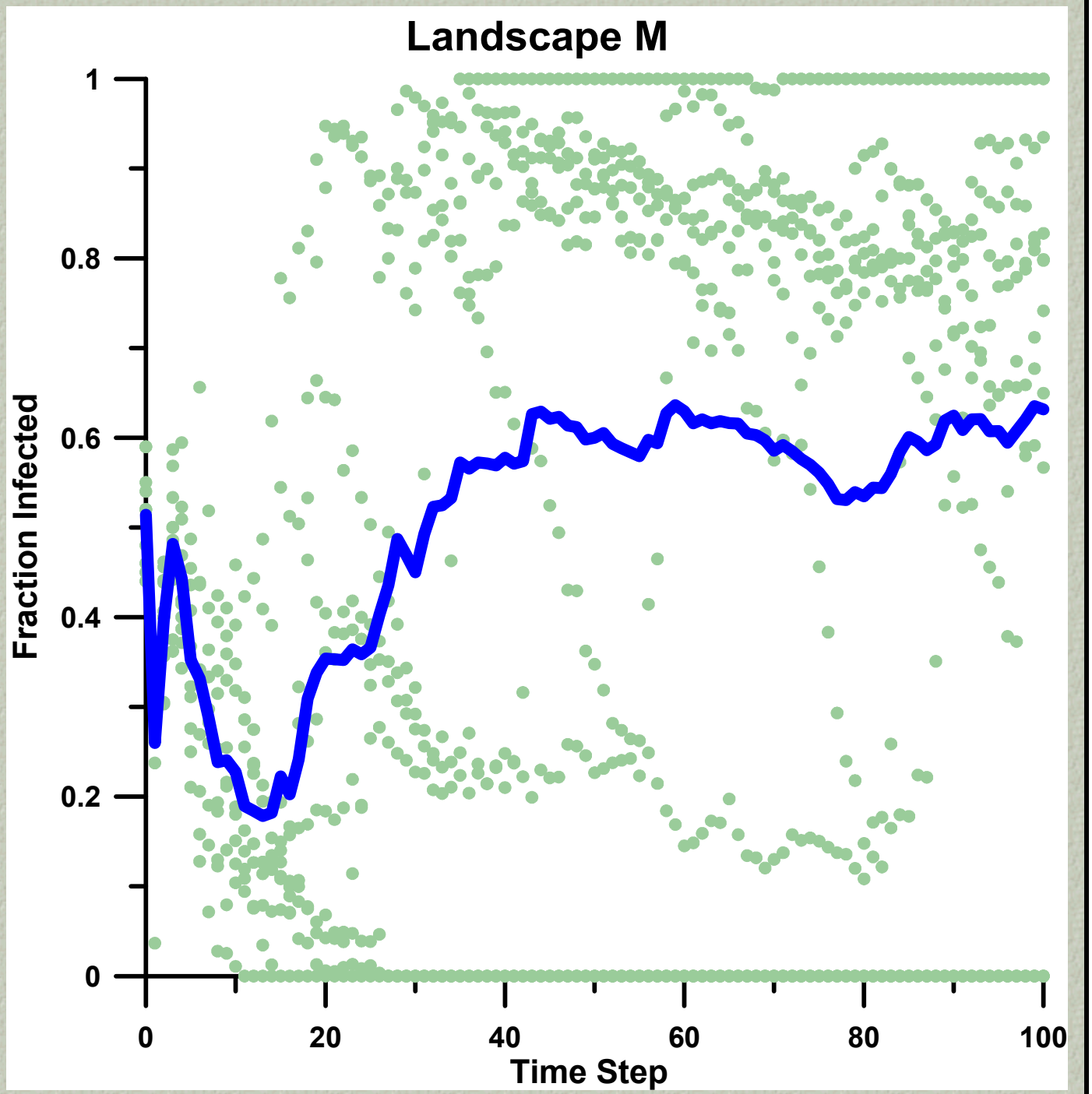


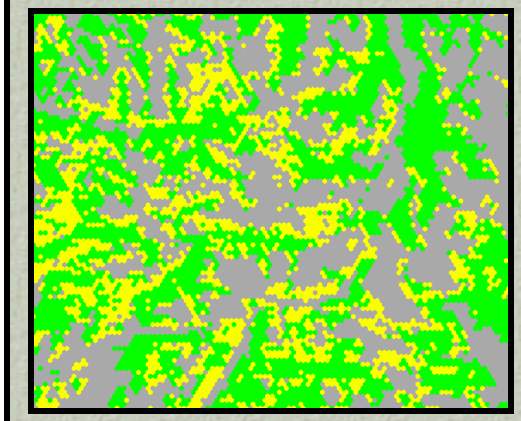
Disease Mortality = 0.20
(Data from 5 Replicates)



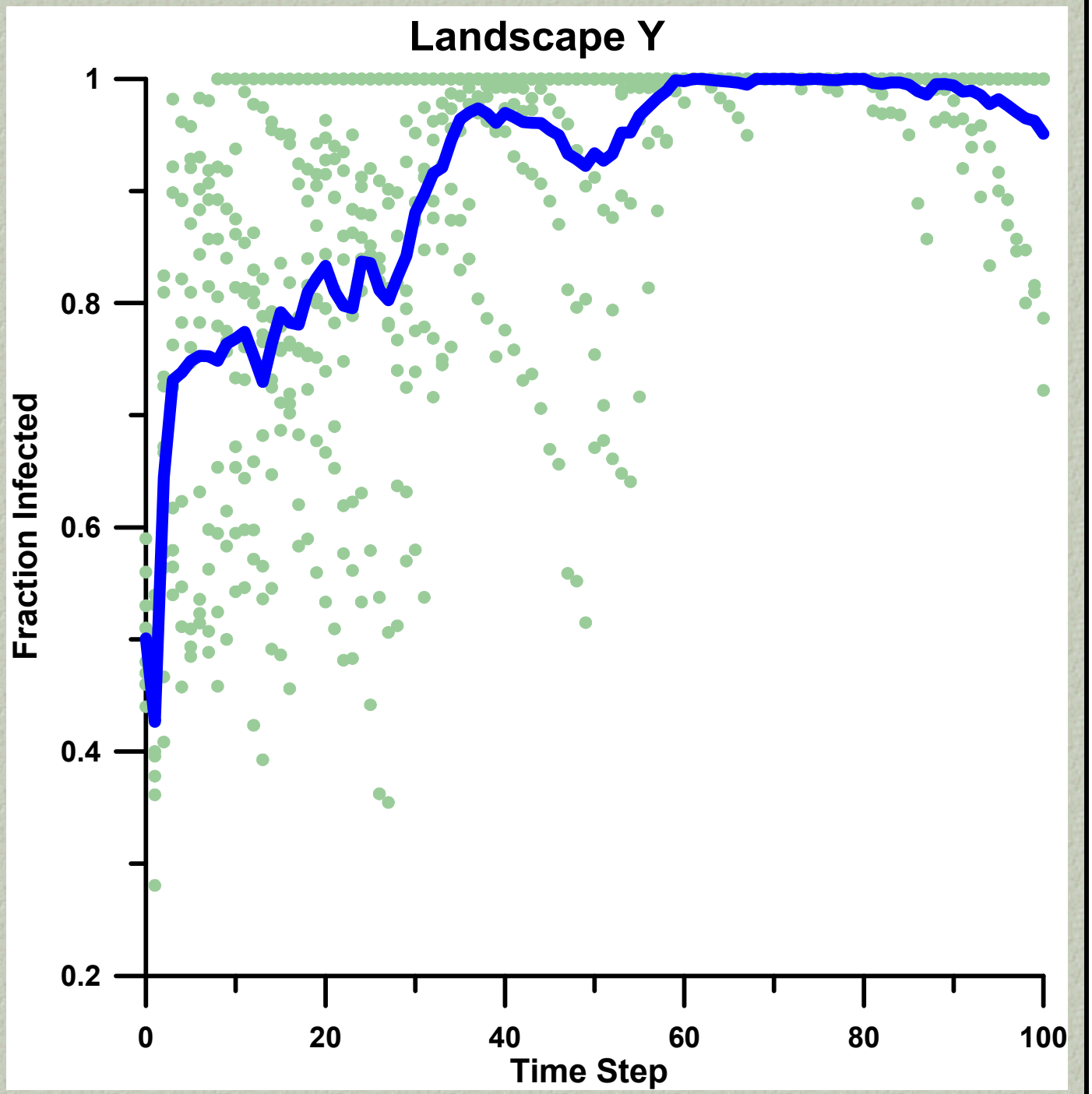


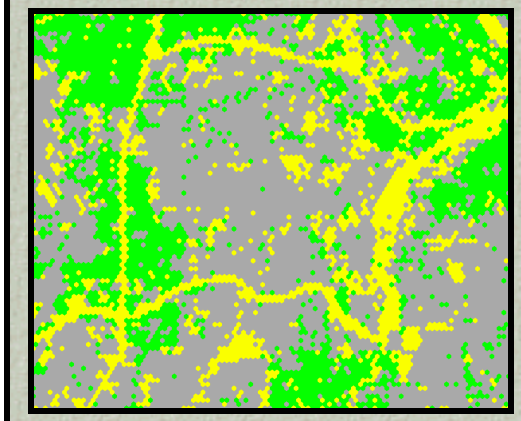
Disease Mortality = 0.20
(Data from 5 Replicates)



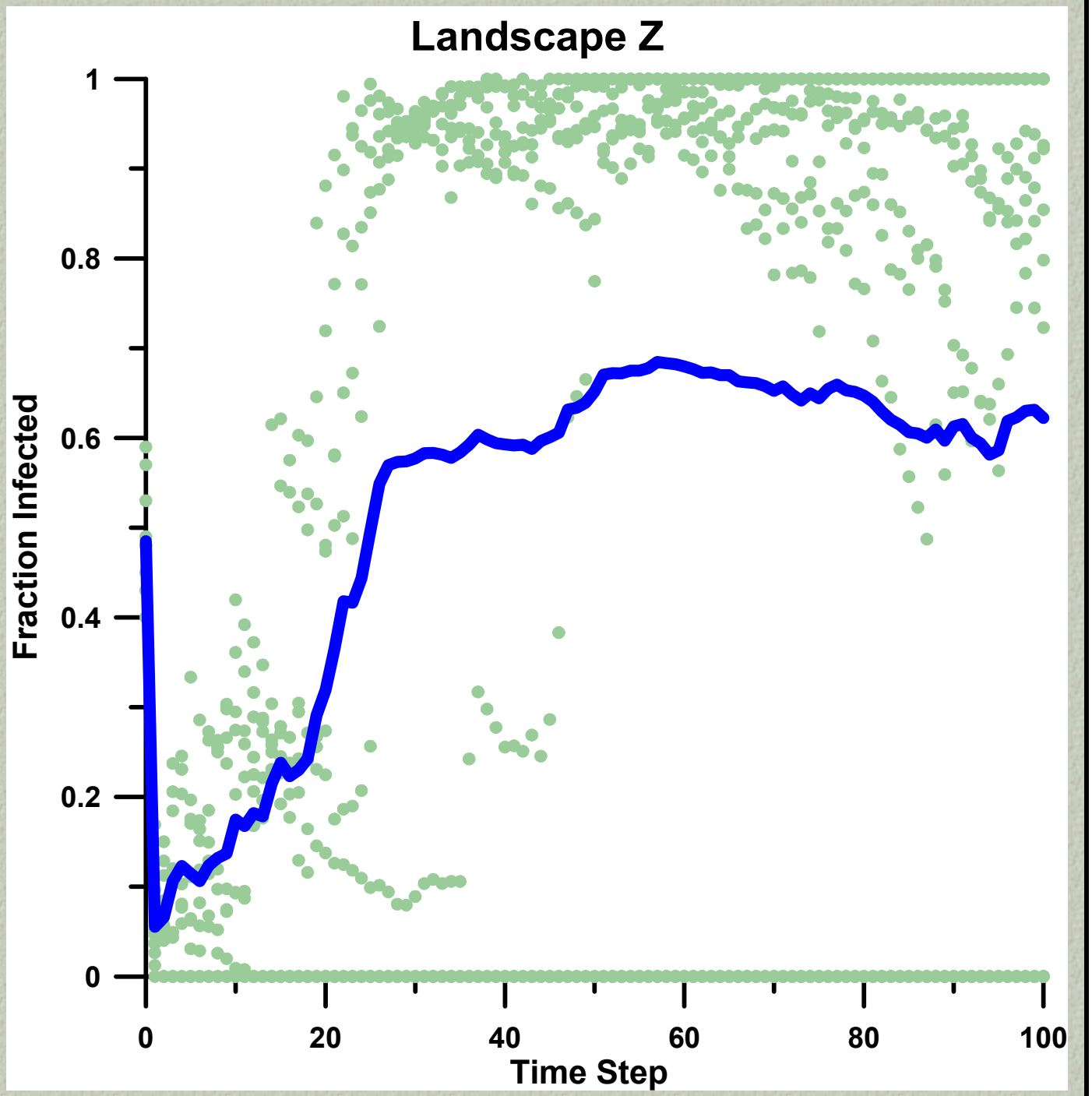


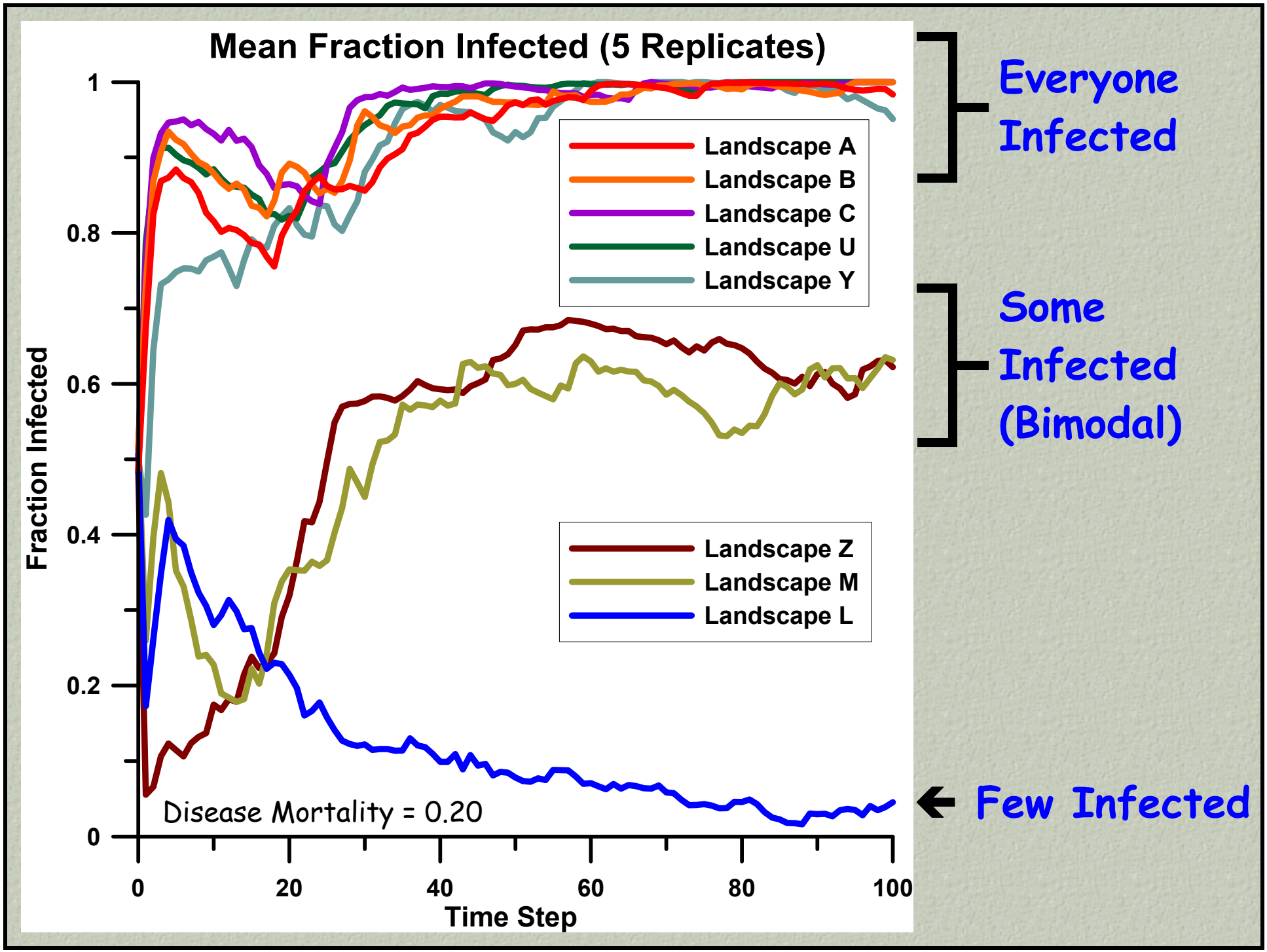
Disease Mortality = 0.20
(Data from 5 Replicates)





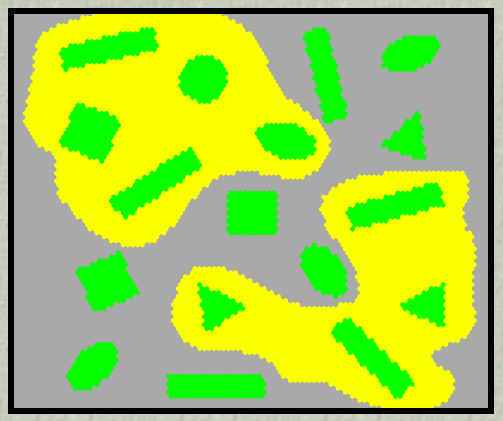
Disease Mortality = 0.20
(Data from 5 Replicates)

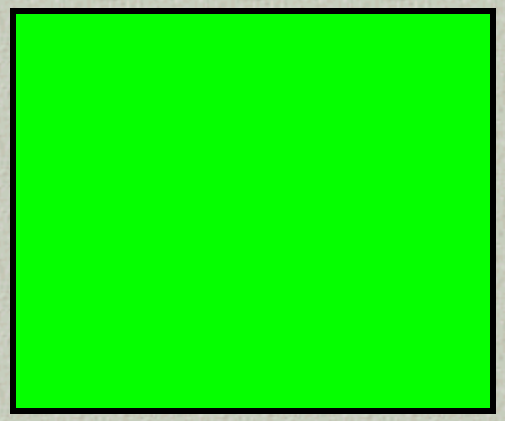


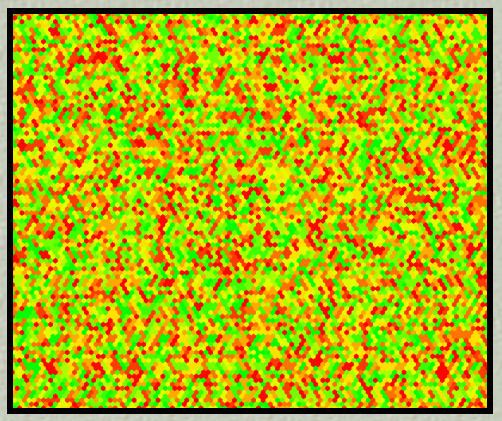

Mean Fraction Infected (5 Replicates)
Fraction Infected
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time Step
Landscape A
Landscape B
Landscape C
Landscape U
Landscape Y
Landscape Z
Landscape M
Landscape L
Disease Mortality = 0.20
Everyone Infected
Some Infected (Bimodal)
Few Infected

Bimodal

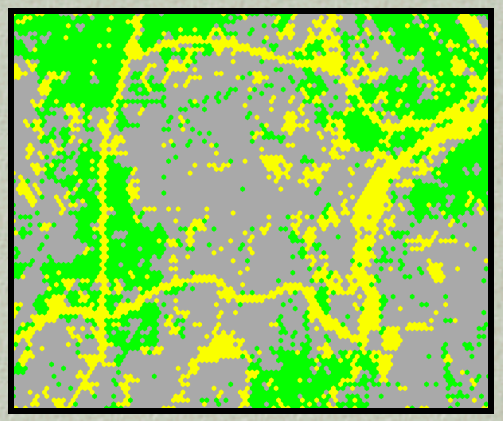
Everyone Infected

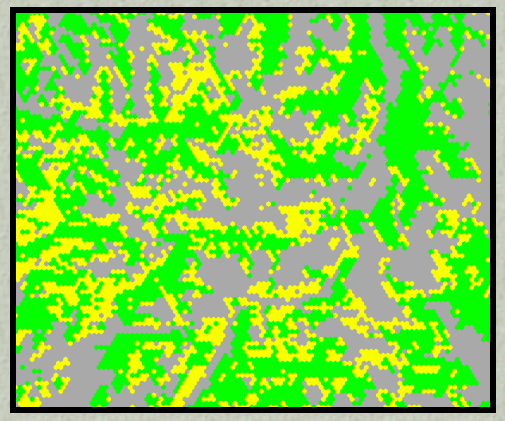


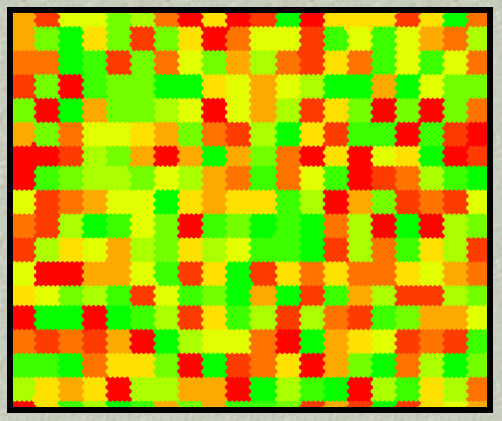


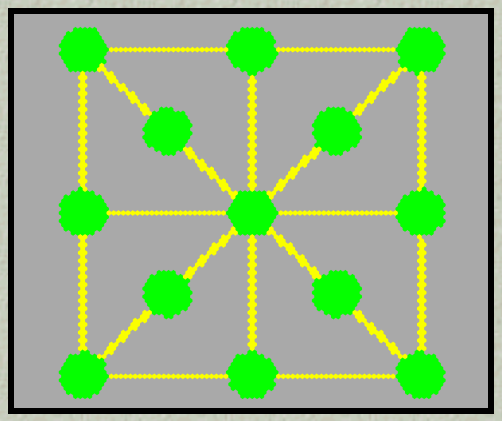


Disease Mortality = 20%

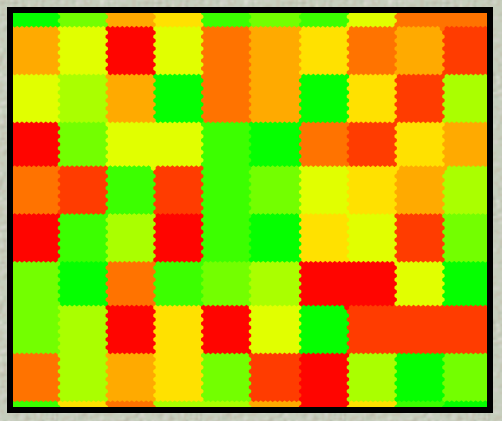








Few Infected



Quick Recap

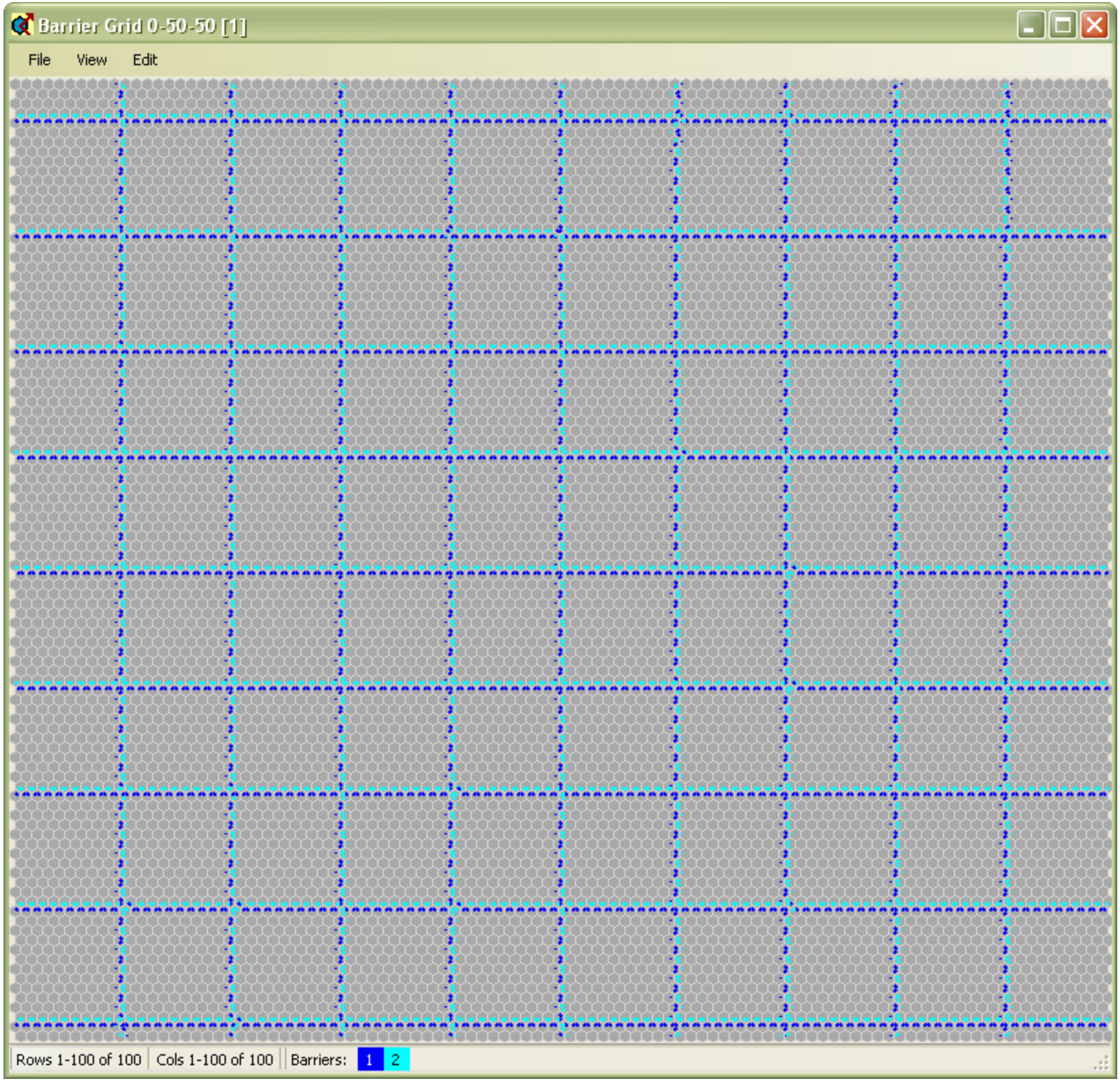
We have looked at the impact of disease on population dynamics in 8 model landscapes

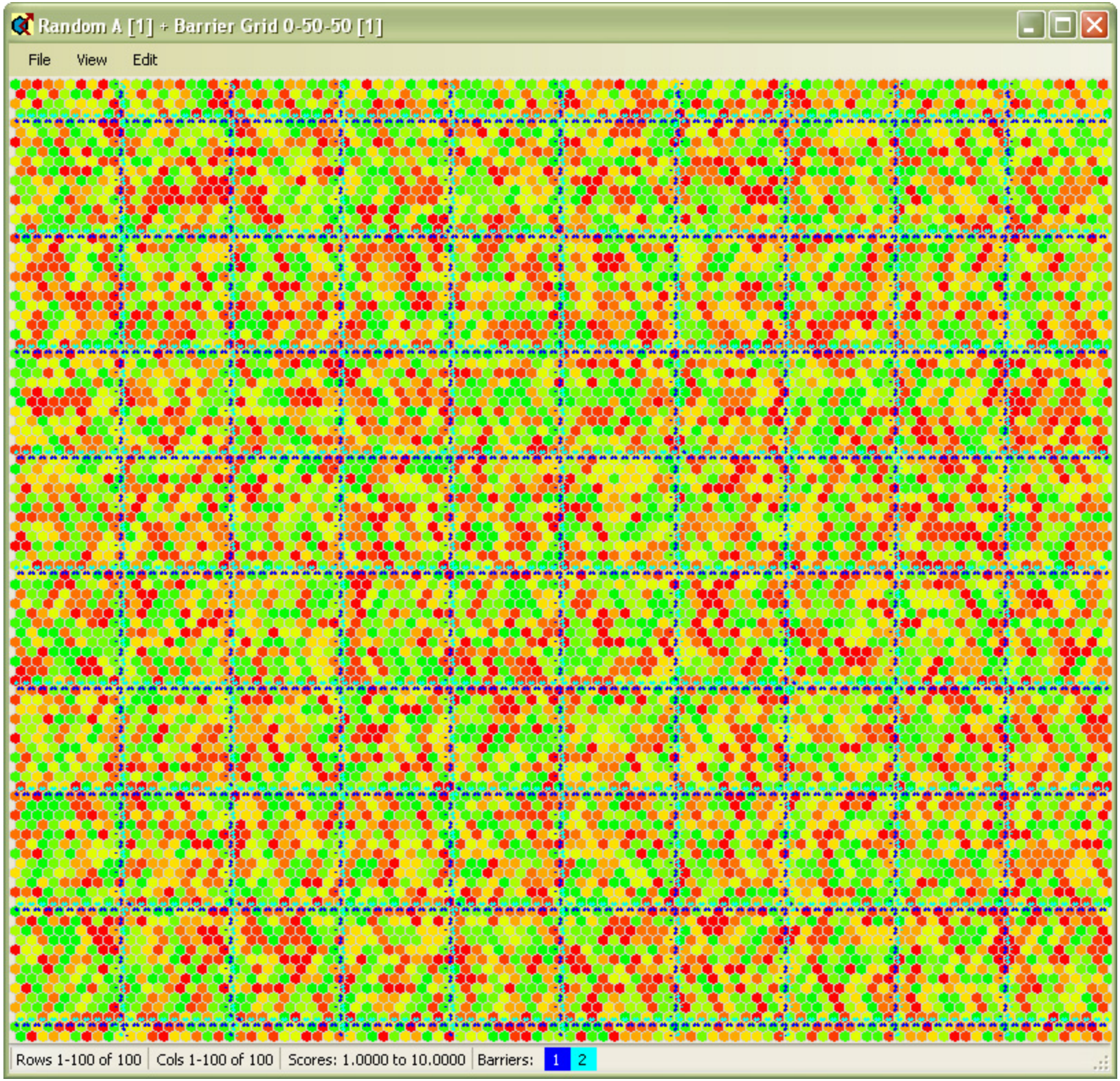
- Landscapes L, M, and Z seemed to be outliers
- Disease had minimal impact on L's pop-size
- Disease had limited impact on M & Z's pop-size
- This was mirrored in the %-infected results

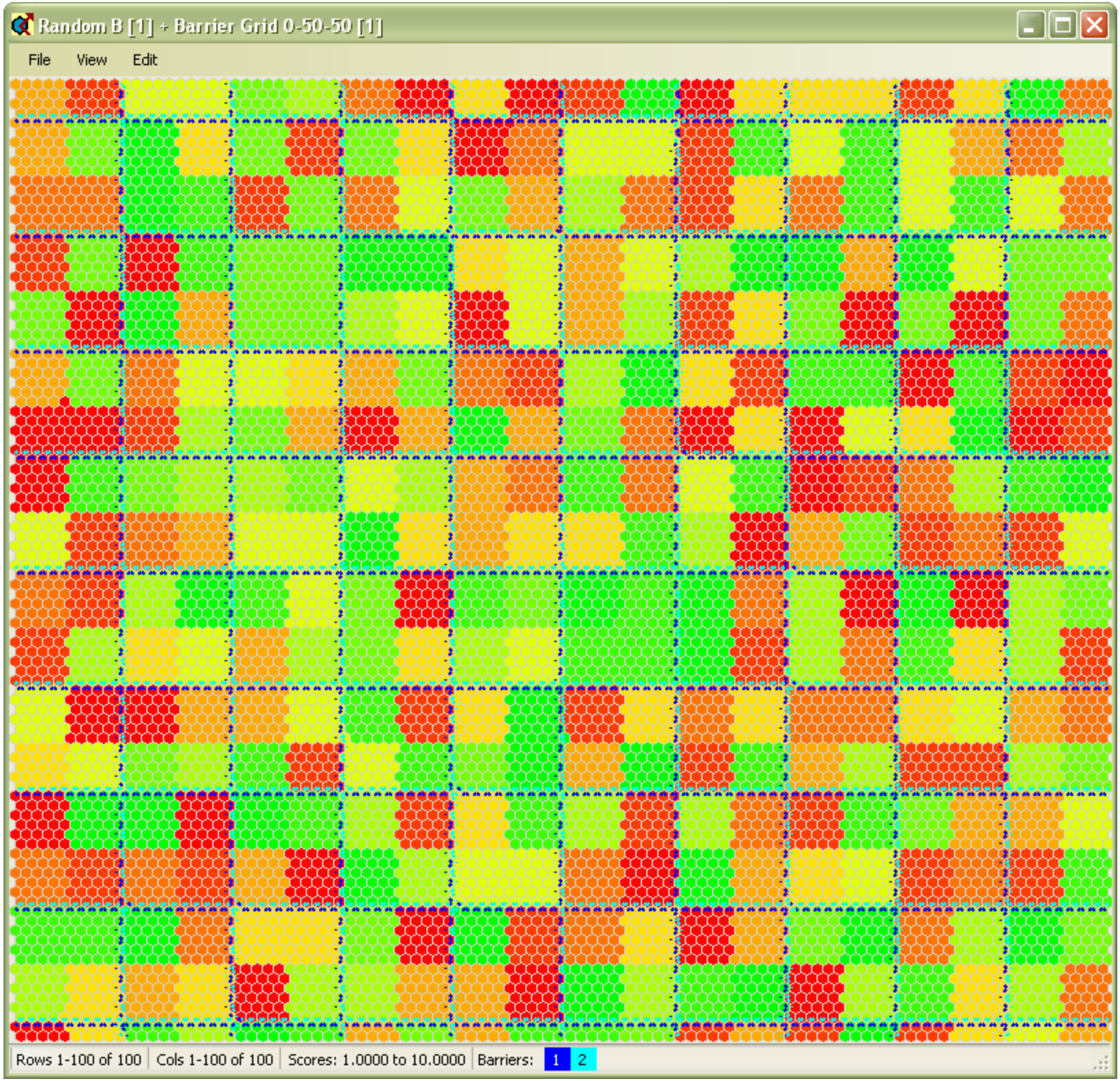
Some Experiments With Connectivity

First -- add a reflecting barrier grid to landscapes *A*, B, and *C*

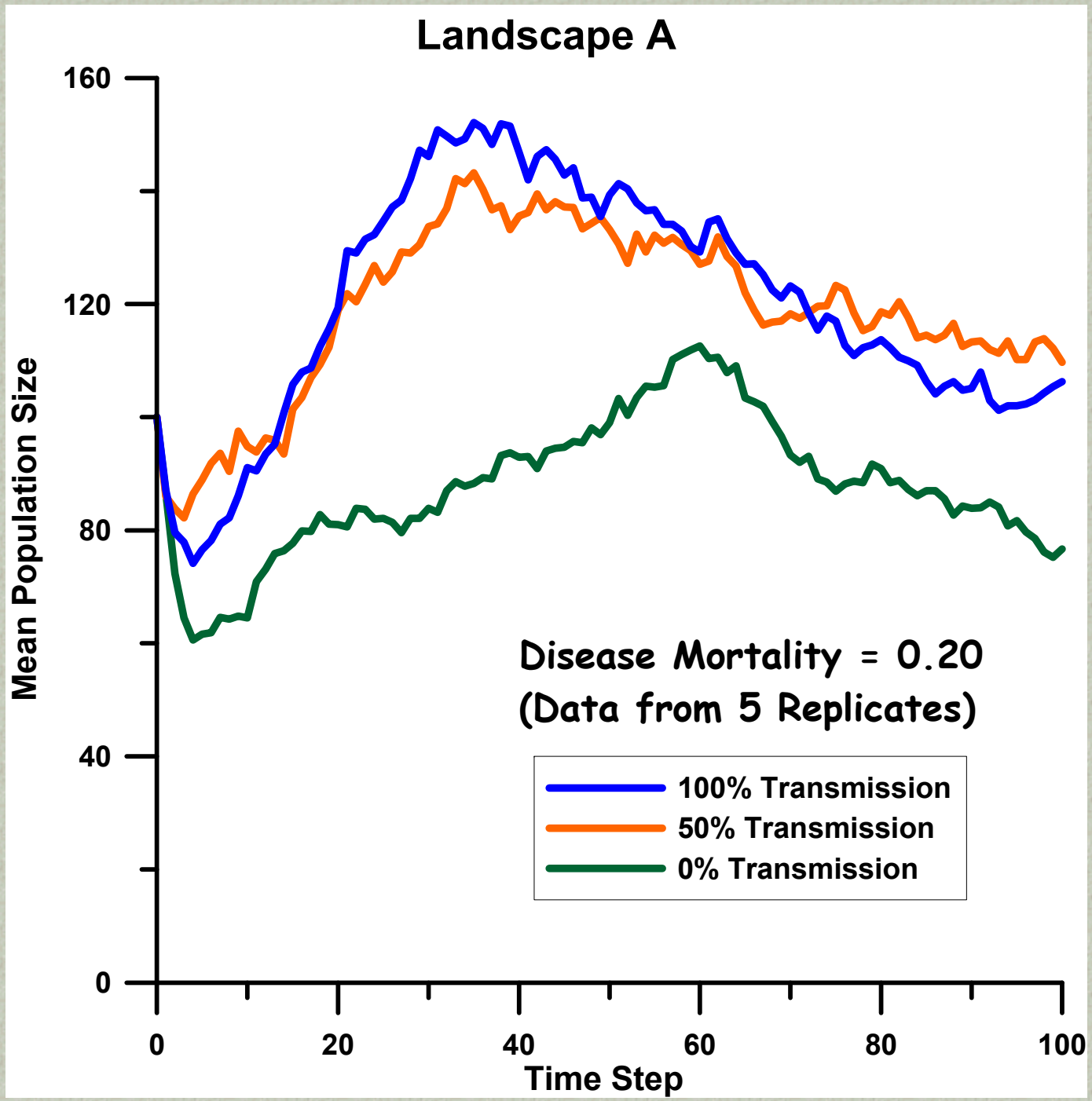
Second -- add an absorbing barrier region to landscape Z

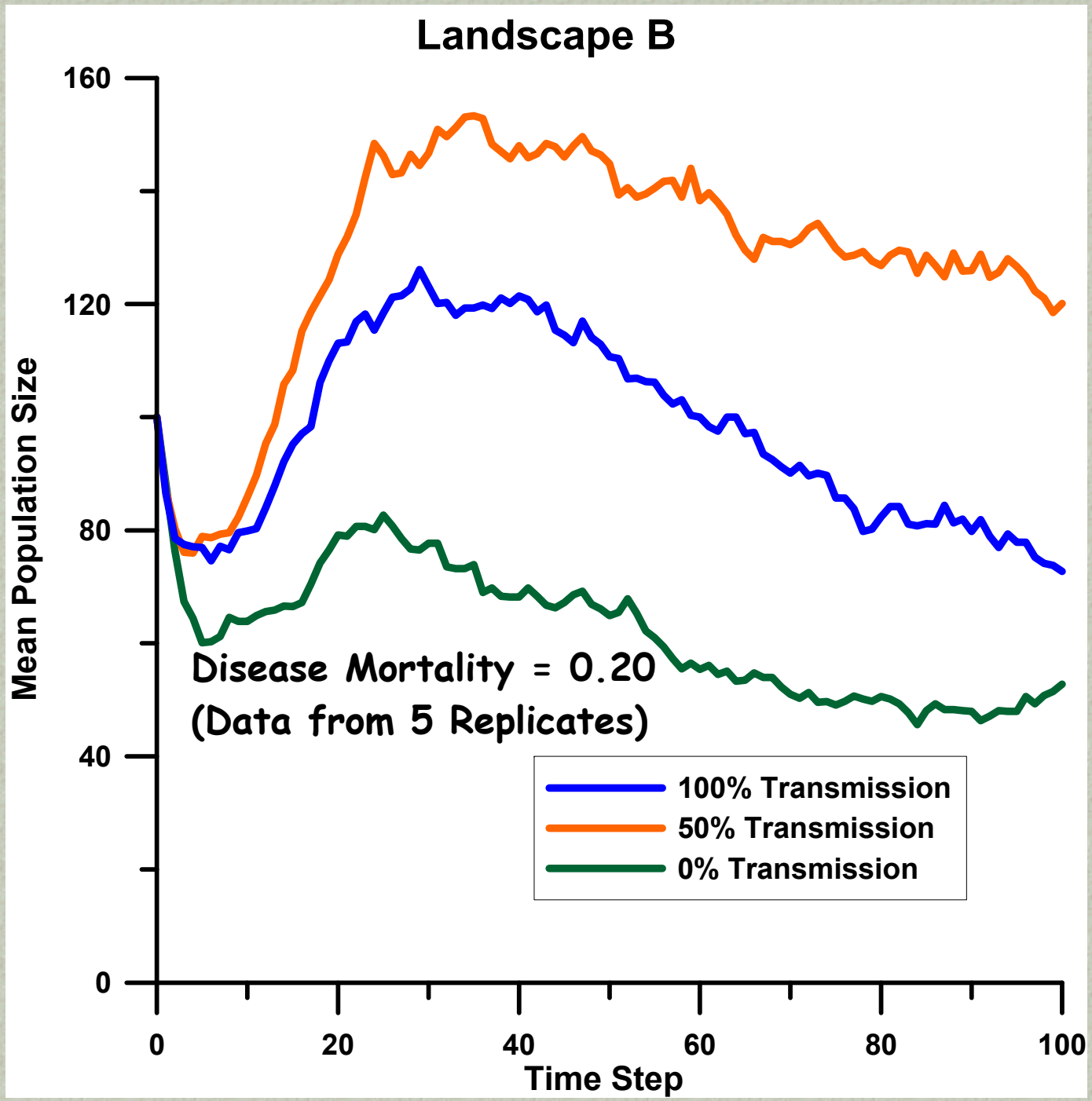

Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Barriers:
1
2

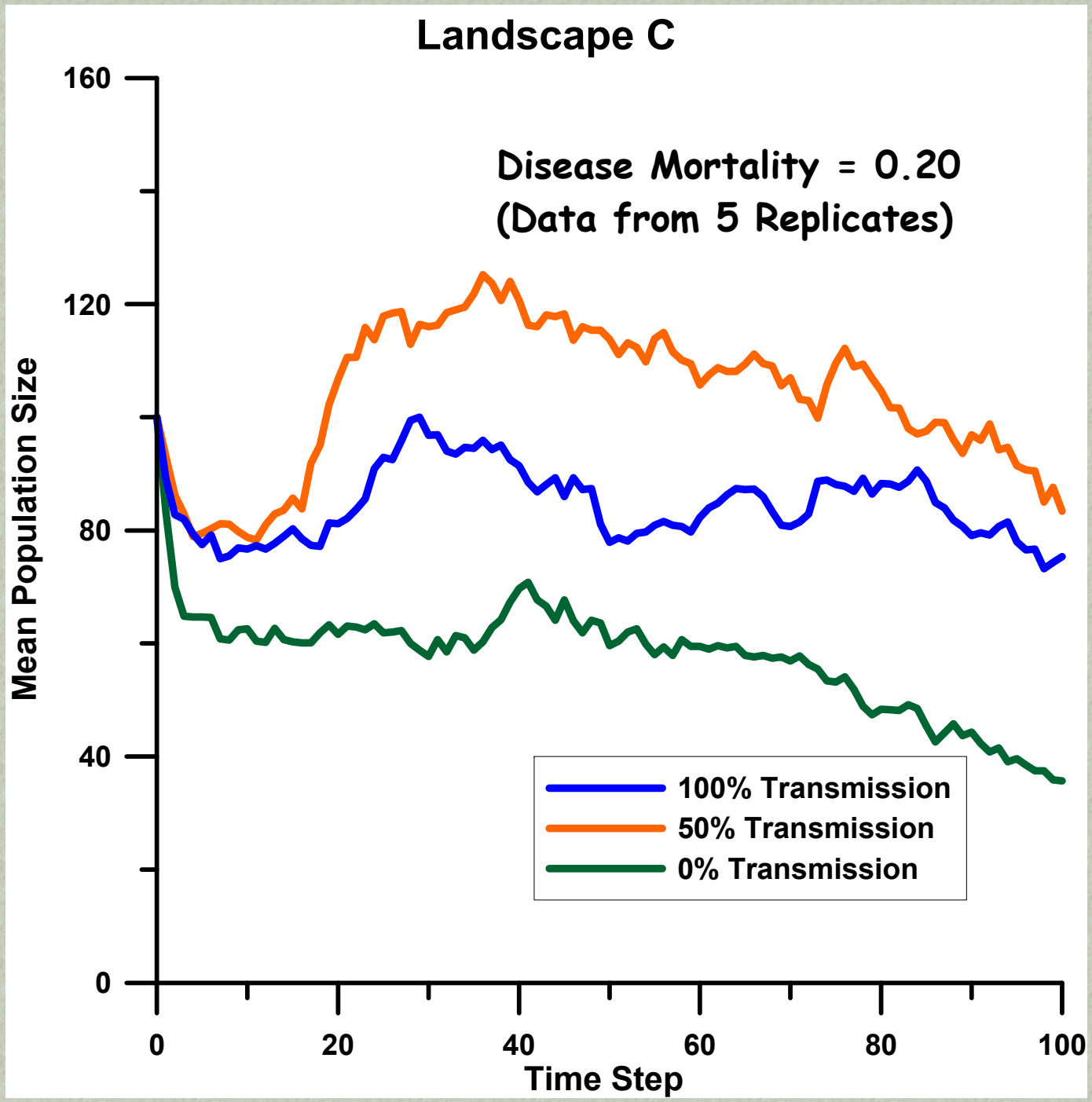

Random A [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

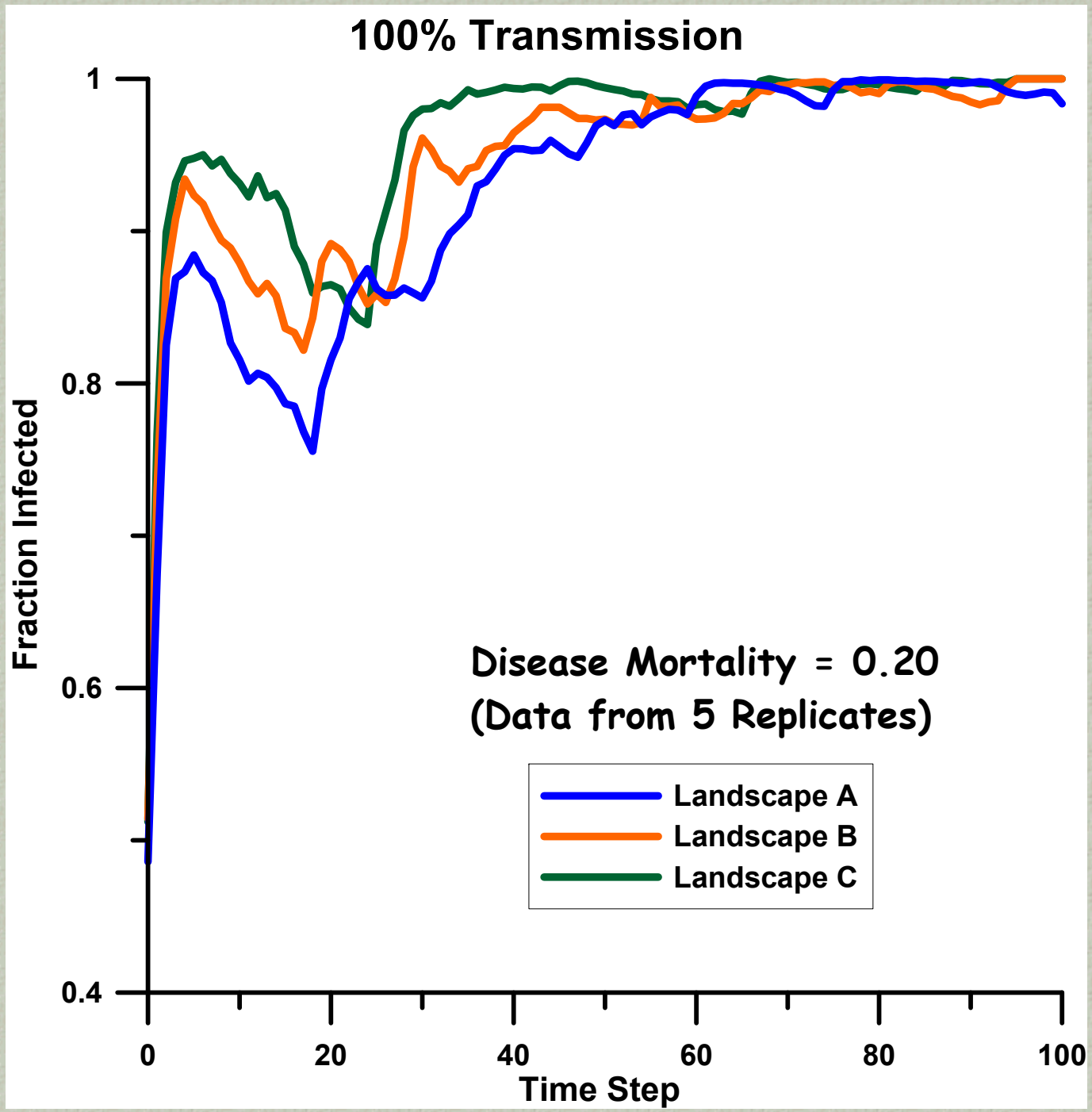

Random B [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

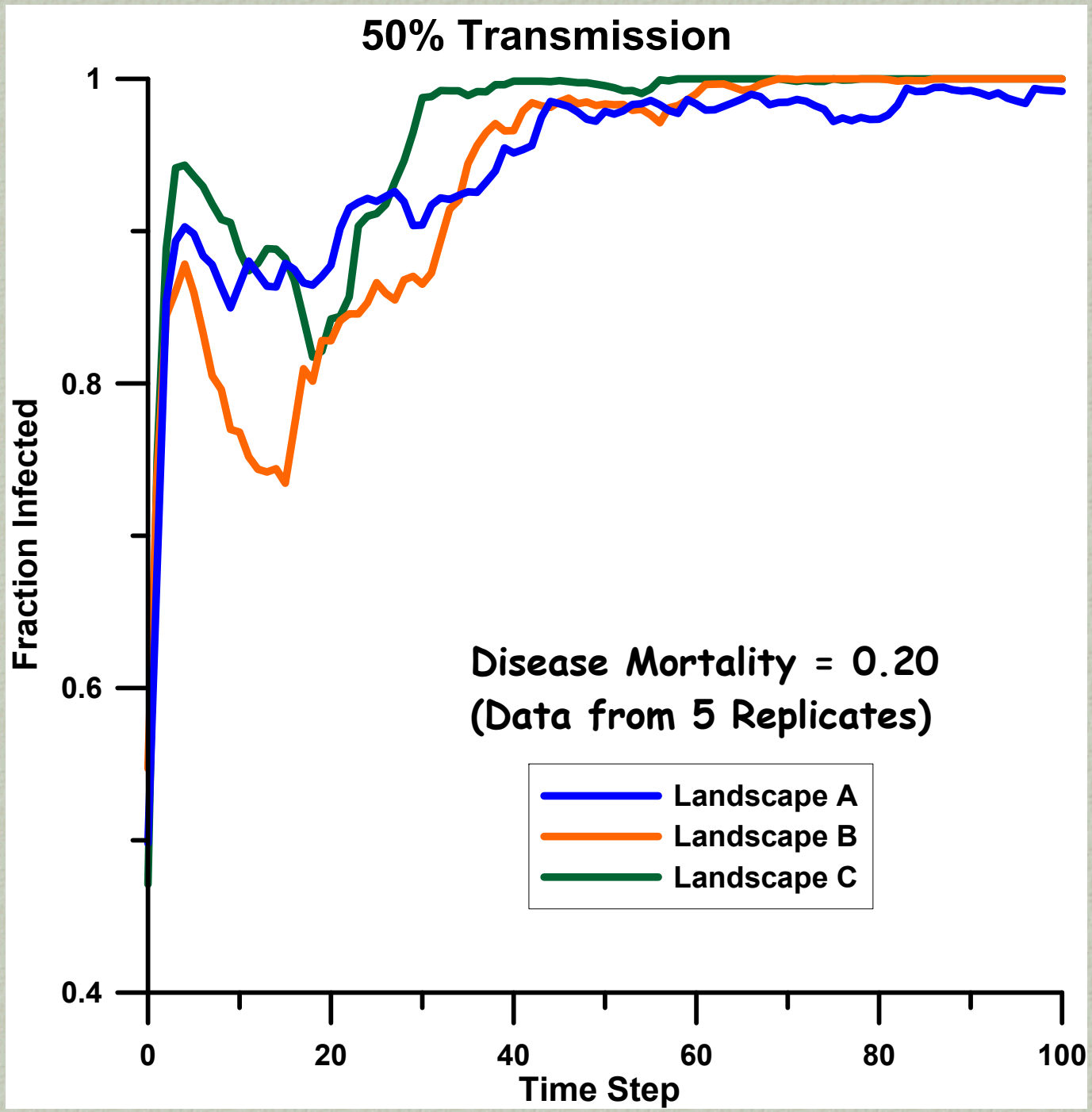

Random C [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

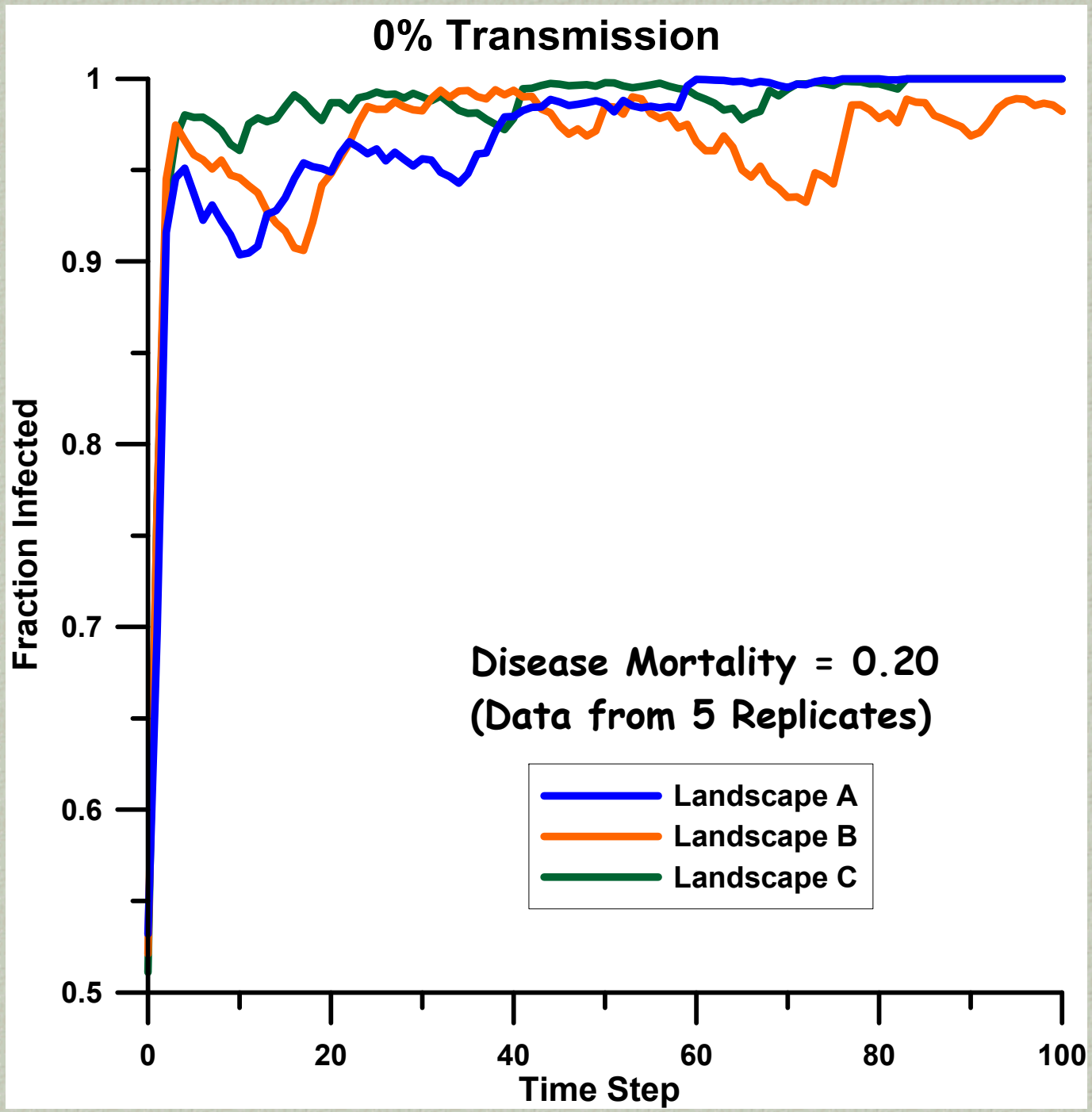

Landscape A
160
120
80
40
0
Mean Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
100% Transmission
50% Transmission
0% Transmission


Landscape B
Mean Population Size
160
120
80
40
0
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
100% Transmission
50% Transmission
0% Transmission


Landscape C
Disease Mortality = 0.20
(Data from 5 Replicates)
Mean Population Size
160
120
80
40
0
0
20
40
60
80
100
Time Step
100% Transmission
50% Transmission
0% Transmission


100% Transmission
Fraction Infected
1
0.8
0.6
0.4
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

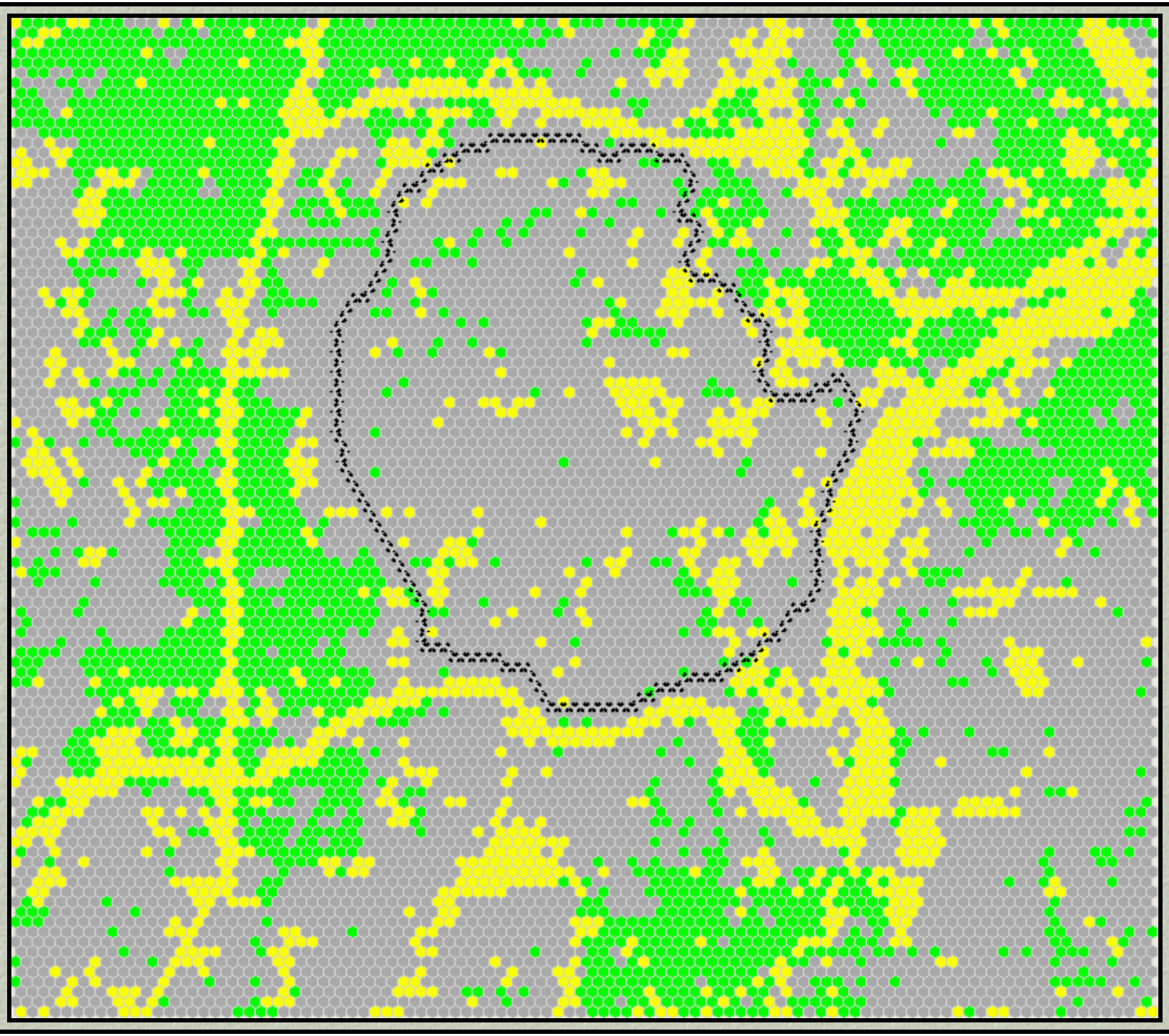

50% Transmission
Fraction Infected
1
0.8
0.6
0.4
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

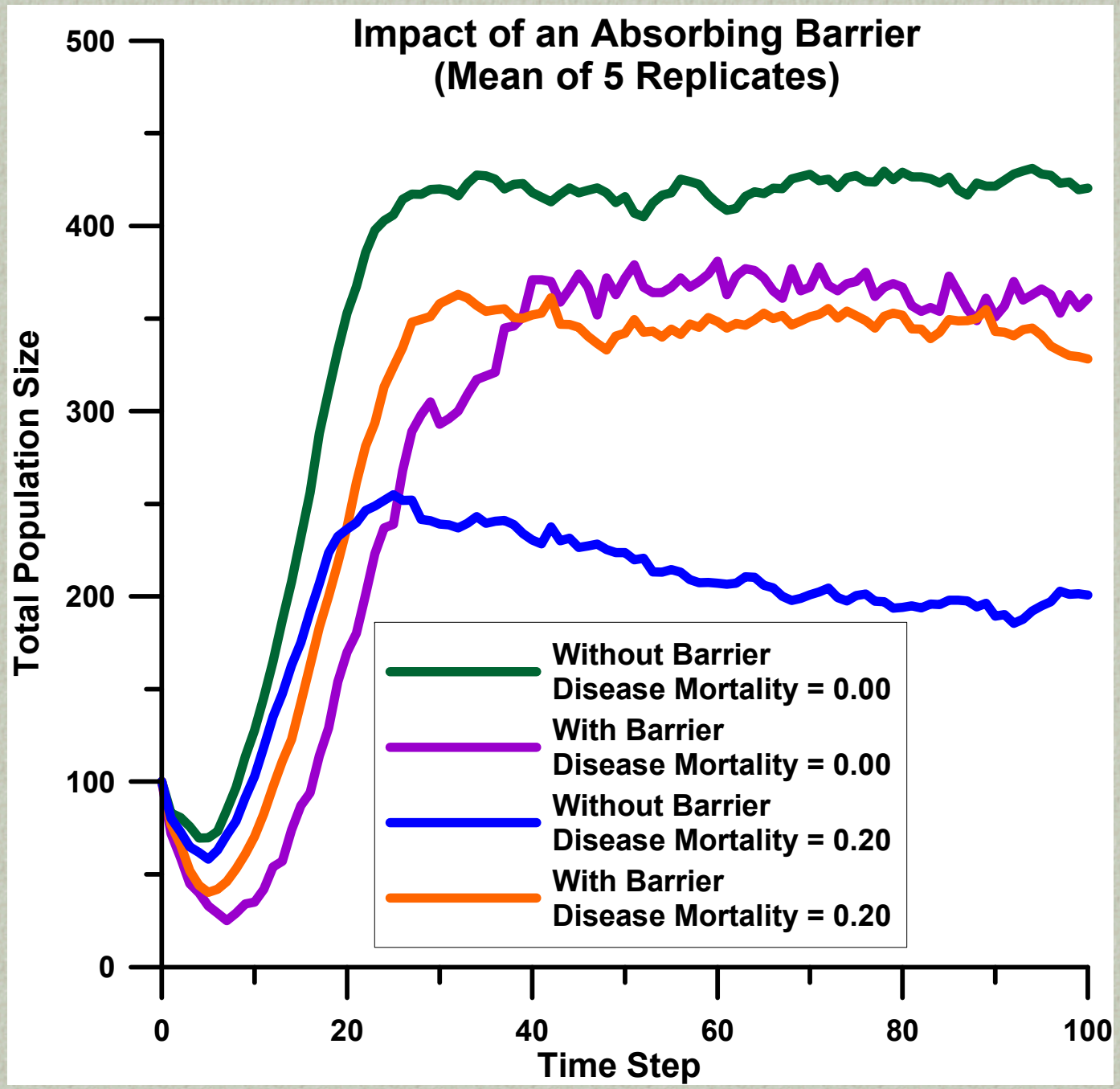

0% Transmission
Fraction Infected
1
0.9
0.8
0.7
0.6
0.5
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

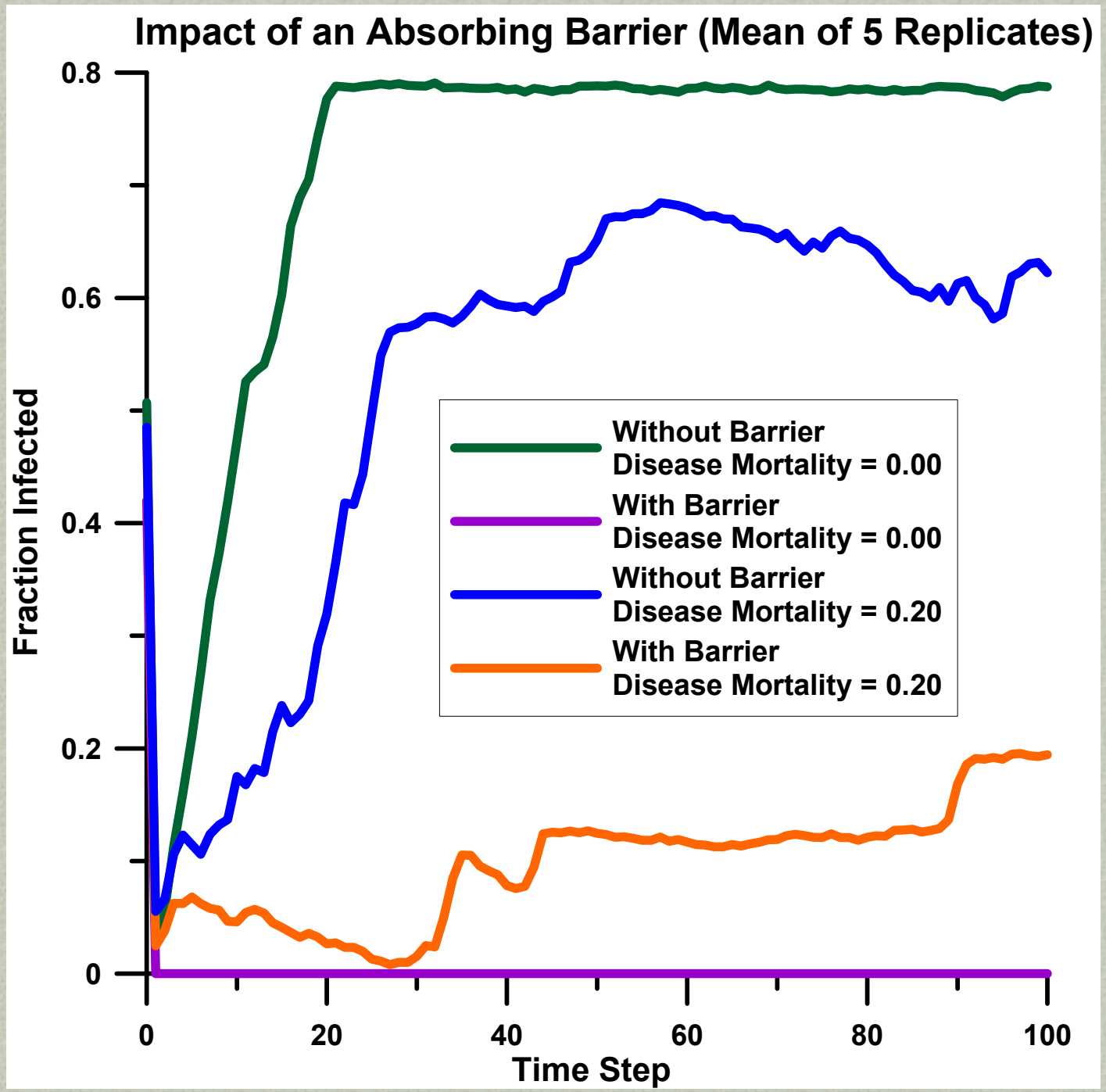
Impact Of An Absorbing Barrier

Movement from the inside out is unimpeded
Movement from the outside in causes death

For each landscape, a simulation was run with
Disease mortality = 20% only




Impact of an Absorbing Barrier
(Mean of 5 Replicates)
Total Population Size
Time Step
0
100
200
300
400
500
0
20
40
60
80
100
Without Barrier
Disease Mortality = 0.00
With Barrier
Disease Mortality = 0.00
Without Barrier
Disease Mortality = 0.20
With Barrier
Disease Mortality = 0.20


Impact of an Absorbing Barrier (Mean of 5 Replicates)
Fraction Infected
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time Step
Without Barrier
Disease Mortality = 0.00
With Barrier
Disease Mortality = 0.00
Without Barrier
Disease Mortality = 0.20
With Barrier
Disease Mortality = 0.20

Quick Recap

We have looked at the impact of reflecting and absorbing barriers on the disease model

- Population size did vary significantly with landscape structure (*A*, B, *C*) and connectivity
- When the disease lowered survival, the absorbing barrier had an unexpected impact